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Sediments Yields in Saimo Catchment of Tugen Hills in Baringo County, Kenya

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Abstract

Soil erosion by water is one of the primary causes of land degradation and occurs throughout the world. Soil erosion contributes negatively to the already declining agricultural productivity thereby negatively impacting on people's livelihoods and economic empowerment in Baringo County. There is need therefore, to understand the erosion processes and quantify sediment yield from catchments in order to propose technically viable, economically achievable and environmentally sustainable mitigation measures. This study focused on estimation of sediment yield from Tugen Hills particularly in Saimo catchment in Baringo County. Run-off plots measuring 5metres by 2metres with average slope of 17% were set up in the catchment, a bean crop was planted under three tillage treatments; conventional, mulching and control. These were done in triplicates in a randomized complete block design yielding nine run-off plots. Soil erosion parameters: run-off volume (Q) and peak flow rate (q_p) were determined from the run-off plots in the catchment. Soil erodibility (K) was calculated mathematically based on soil samples collected and analyzed in the laboratory. Cover management (C) and support practice (P) factors were determined through observation and use of conversion tables. In terms of results, mean bulk densities for top soil and bottom soil were 1.05g/cm^3 and 1.07 g/cm^3 respectively meaning that low bulk densities for the top soil. The total value for fine sand and silt was 37.1%. The saturated hydraulic conductivity varied from 8.0 µm/s to 41.3 µm/s with a mean value of 24.1 µm/s. There were only two classes high and moderately high translating to code 2 and 3, respectively. Block three under no planting (control) had the highest percent cover (93%) towards the end of the growing season. The maximum sediments for each day had the highest value of 414 grams observed in block 2 with mulching. The MUSLE model did not accurately predict surface run-off and sediments yield compared to field data. Plots under cover crops had reduced soil erosion and lesser sedimentation yield. Future work is needed for new plots under different slopes.

Keywords: Baringo County, Tugen Hills, Erosion, Slope, Soil Erosion Parameters

INTRODUCTION

Soil erosion is defined as the process of detachment and transportation of soil materials by erosive agents (Foster and Meyer, 1972) leading to degradation of 65% of agricultural land in Africa consequently leading to sedimentation in reservoirs (Gwapedza et al., 2021). Soil erosion can take several forms like rill, splash, sheet and even gulley erosion (Sun et al., 2021). Sedimentation of reservoirs reduces the economic life and lifespan of the water bodies as has been witnessed in the siltation of Kamnarok lake in Baringo. The rising of water levels in various lakes and dams in Kenya in 2020 during heavy rainfall can be linked to siltation.

Erosion leads to transportation of soil particles in suspension thus affecting the turbidity of water as was observed in the neighboring county of Elgeyo-Marakwet (Mbaka et al, 2017). Turbidity of water is a form of water pollution and affects light penetration as well as cost of water treatment (Mbaka et al., 2017). Though soil erosion is not good for the source areas, it can be good for low lying areas because of alluvial deposits that make the lands fertile as was observed by Cheboi et al., (2021) in Homabay County in Kenya. Therefore, to protect the finite and precious water resource there is need for control of erosion to realize the attainment of the Sustainable Development Goal number six of the United Nations. Realization of the goal is hinged on protection of the ecosystems to avoid a quarter of world population in 2050 experience of recurring water shortages (https://www.undp.org/sustainable-development-goals).

Studies of soil erosion can be achieved using two principal methods; on one hand physical model where a run-off plot is used and on the other hand use of mathematical models.

Erosion, transportation and deposition vary in terms of space and time thus becoming costly when one is interested in getting representative samples that can be used to calibrate various mathematical models for predicting erosion. It is imperative that there be a development of baseline information globally to capture soil-erosion model applications and validation. The model that is used mostly in soil erosion numerical modelling is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1960) and further developed by Williams (1975), transformed to Modified-USLE in 1977 called MUSLE with further development by Renard (1997) for USA application and named Revised-USLE called RUSLE (Gwapedza et al., 2021).

The factors that are needed by the model to work are climate (rainfall), characteristics of the soil, type of vegetation cover, slope and human factors. Despite numerous studies on plot scale, there still exists challenges in scaling up the model use because of the uncertainties (Borelli et al., 2021). Such uncertainties can be identified and rectified for the improvement of model results by collecting more data from various places in the world that have unique input parameters for the model. In fact, there is need for increased measurements and monitoring programs to enhance the validation of the models (Ezzaouini et al., 2020).

Rainfall intensities and slope of a given area are positively correlated with the amount of sediment yield. The duration of rainfall affects the sediment yields that affect the depth, width and length of rills created by rill erosion. Rill erosion was found to be the main concern in Ansai County in China (Sun et al., 2021).

It is true that erosion studies have generated a lot of interest to many researchers globally and more so in Africa from the South to North. Hategekimana et al., (2020), studied soil erosion in Coastal Kenya, Gwapedza et al., (2021), worked in South Africa while Ezzaouini et al., (2020), did erosion studies in Morocco. Despite all these work there is little information on sedimentation around Tugen hills in Baringo, Kenya. This despite the fact that human settlement, declining vegetation cover and intensive unregulated agriculture are a threat to the future livelihood of the people and livestock in the Tugen hills, Baringo. Increase in human population has led to intensive cultivation of steep slopes for agricultural production. Consequently, the catchment has been stripped of natural vegetation, is intensively cultivated and suffers from soil erosion, decreased infiltration capacity, decreased soil fertility, increased sedimentation of rivers, and high surface run-off rates.

The broad objective of this study was to assess soil erosion in Tugen hills with a view of quantifying the sediment yield under different soil cover. Specific objectives were to determine soils texture, structure, permeability and organic matter hence soil erodibility; slope length and steepness factors to be used in Modified Universal Soil Loss Equation (MUSLE) model, to calibrate and validate the MUSLE model for surface runoff and sediment yield against field data and to simulate sediment yield from the catchment under different scenarios of cover management (C-factor) and support practices (P-factor).

METHODOLOGY

Study Area

Run-off plots were set up in Tugen Hills within Saimo catchment (0.5842^0 N and $35.74\ 00^0$ E, with an altitude of 1625 m above sea level) in Baringo County. The site is located about 320 km from Nairobi city, Kenya. The Tugen Hills are a series of hills in Baringo County, Kenya (see map of Baringo in Fig.1). They are located in the central-western part of Kenya. The Tugen Hills represent one of the few areas in Africa preserving a succession of deposits from the period of between 1 and 4 million years ago, making them an important location for the study of human (and animal) evolution. Excavations at the site conducted by Richard Leakey and others have yielded a complete skeleton of a 1.5-million-year-old elephant (1967), a new species of monkey (1969) and fossil remains of hominids from 1 to 2 million years ago. (Senut et al., 2001).

Rainfall is of bimodal type with long rains occurring between April to August and short rains between September and November with an average of 1000 mm/yr. Maximum average temperature in the area is 28^0C occurring between February and March while the minimum average temperature is about 11^0C and occurs between the months of December and January. Soils here are majorly classified as Leptosols (weak developed shallow soils). The area is relatively steep with dominant agricultural practices being growing of maize, fodder and small-scale livestock farming. Access to the area is via Kabarnet - Kabartonjo road and about 15 km from Kabarnet town.

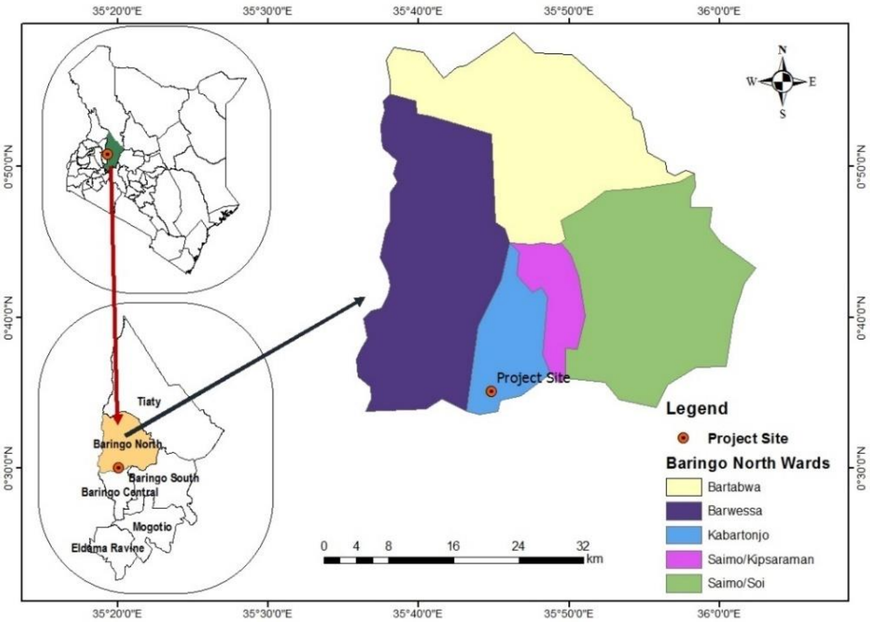

Figure 2: Maps showing Baringo County and project site.

The treatments comprised of three tillage practices (conventional, mulching and control) in a randomized complete block design (RCBD), with three replicates. Each replicate had 3 treatments and a unit plot measured 5 m × 2 m. The distance between plots was 30 cm (Fig 2). The plots were allocated by casting lots. Assignment started from West to East. The run-off plots were sloping from North to South. In Figure 2, B stands for Blocks. The area was divided into three blocks. T in the figure stands for treatments, T1(no mulch), T2(mulched) and T3 (Control).

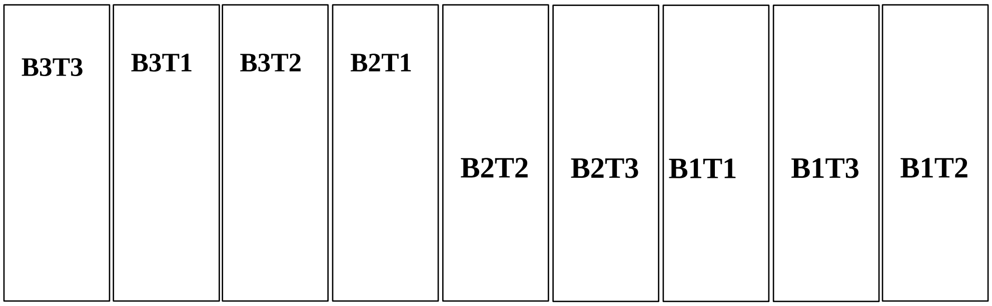

Figure 3: Experimental layout.

Slope of the Project Site

The general gradient of the project site was determined by use of line level. Levels of three points within the proposed project set up area were taken and an average of 17% obtained. Verification was done by using a clinometer.

Installation of Run-off Plots

In preparation for installation of run-off plots, a leveling exercise was carried out to establish the general slope of the area. Galvanized metallic sheets of gauge 24 were used to construct all the run-off plots. These sheets were cut into strips of 30cm in thickness and buried 10cm below the ground surface. The border joints were then flapped firmly together and soil compacted gently along the boundary walls. An apron of 20cm was installed downstream of the run-off plot to cover the entire width providing smooth connection between the ground and the run-off collector. The collector was then overlapped with the apron to concentrate and direct the run-off and sediments through a delivery pipe of four inches to a covered collection tank of 20 litres capacity (Fig. 3). A cut off drain of 0.25% slope was done upstream to safely discharge run-off from entering experimental site. In the downstream, a retention ditch of 0.8m and 0.6m deep was done to allow the positioning of the collection container.

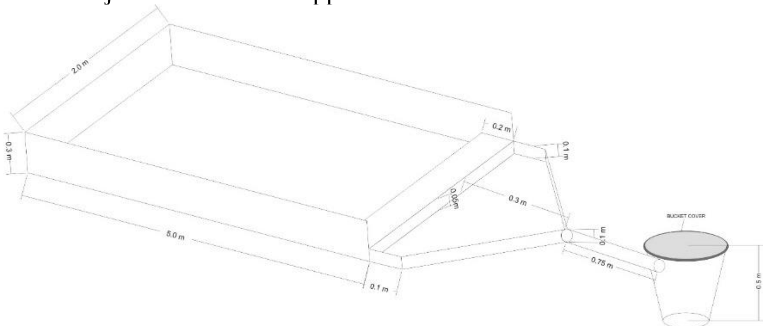

Figure 4: Complete run-off plot layout.

Run-off Plots

Run-off plots of 5m long by 2m wide were developed (Fig 3). The plots were established adjacent to one another with the long axis (length) perpendicular to the contours. The plots were isolated using metallic plain sheet partitions. The run-off was channeled out of the plot by means of a metallic apron and a 4’’ PVC pipe to a collection tank of 20 litres capacity at the downslope end.

Land Preparation

The plots were ploughed conventionally using hand hoe (Jembe) along the contour after the installation of boundary metal sheets. A uniform plough depth of 8 inches was achieved. Extra care was taken not to move the soil further from its original position and not to disorient the boundary sheets.

Figure 5: Photos of prepared run-off plots.

Soil Sampling within the Run-off Plots

Soil samples were collected randomly in three points within the experimental site. These three points were at the extreme ends and at the middle of the run-off plots. Soil sample rings were used to collect undisturbed soils at 0-10 cm and 20-40 cm. The soils were then analyzed for physical and chemical properties; soil texture, soil structure, permeability and organic carbon.

Bean Crop Establishment

Rose coco variety of bean was planted on the two plots and one unploughed plot left as control. These plots under bean crop as plant cover and control (no crop planted) were replicated three times. Two seeds were placed in a 1-inch-deep hole. DAP fertilizer was applied at a rate of 50 kg/ha. A spacing of 45 cm between the rows and 15 cm between holes was maintained in all the plots planted. Weeding was done by use of hand hoe two weeks after germination and on the start of flowering stage on the plots with no mulch. Pesticide to control black bean aphids was sprayed in all plots with mulch and no mulch. Mulching was done using hay grass as mulch material. The mulch was placed uniformly in the entire plot with mulch treatment one and half weeks after germination and at about 3.5 inches above the ground.

Run-off and Sediment Sampling

Sediment Collection

Sediments were collected and recorded after every rainfall event. The automatic rain recorder was used and manual rainguage (Fig. 5b) used as a check. After every rainfall, run-off generated was collected in 20 litres containers, measured, recorded and emptied. Prior to collection of the run-off and measuring, the apron part of the run-off plot was cleaned thoroughly using the run-off water already in the container. After which, the mixture was thoroughly mixed and measured to record total volume of run-off. The portion of this run-off was taken to the laboratory for measurement of sediments.

a **b**

Figure 6: Run-off collection (a) and rain gauge installation (b).

A representative run-off sample was shaken thoroughly and 5ml of hydrochloric acid added to promote the flocculation of the suspended solids in the laboratory. The mixture was then left for 24 hours to facilitate complete settlement of suspended solids and thereafter the supernatant water discarded carefully. The remaining wet sediments were oven dried for seven hours at 105°C and sediment concentration determined as the dry mass of sediments divided by the volume of sample.

Determination of run-off (Q) was done by measuring the contents of the collection tank after the rain and after overland flow had stopped. Peak flow rate was done using the equation

To estimate peak flow rate, equation (1) was used:

$$q_p = \frac{1}{3.6} CiA \qquad (1)$$

Where;
$q_p =$ Peak run-off rate (m^3/s)
C = Run-off coefficient
i = Rainfall intensity (mm/h)
A = Area (km^2)

Rainfall data was obtained from automatic tipping rain recorder installed within the experimental site. Manual rain gauge was also installed next to automatic rain gauge to act as control.

Soil erodibility, K-factor was calculated using the equation below.

The values for the measured soil properties were used to calculate K using equation 2 below.

$$K = \frac{[2.1\times10^{-4}(12-MO)M^{1.14}+3.25(S-2)+2.5(P-3)]}{10} \qquad (2)$$

Where K is the soil erodibility expressed in t.ha.hour/ha.MJ.mm in which t stands for tonnes, ha (hectare), MJ (mega joule) and mm (millimeter); MO is percentage organic matter; M is textural term for percentage of fine sand plus percent silt; S is the structure class code that varies from 1 to 4 where 1 is for fragmented structure and 4 for coarse structure. P is the permeability code that varies from 1 to 6 (Ezzaouini et al., 2020).

The topography (LS) accounting for run-off length and slope was calculated using the equation (3);

$$LS = L0.5\ (0.0138 + 0.00974Y + 0.001138Y^2) \qquad (3)$$

Where;
Y is the gradient (%) over the run-off length, L is the length (m) of slope from the point of origin of the overland flow to the point where the slope decreases to the extent that

sedimentation begins (plot length). This is however applicable for slopes > 4% (Mishra et al. 2006).

Cover management factor was estimated using vegetation cover conditions in the run-off plots.

At the plot scale, there was no mechanical conservation measure resulting in P value of 1.

RESULTS

Physical and Chemical Properties of Soil

Table 1 shows that, from the six samples, the highest percentage of sand, 55% was found in Point 3-1, the highest silt was found in PT3-2, and the highest clay was 15% found in PT2-2. The textural classes in the study area were sandy loam and loam. The means of sand, silt and clay in the area were 52.2%, 35.3% and 12.5%, respectively. The top soil in study area was sandy loam while the soil at 200 mm was loam.

Table 1: Texture, bulk density, organic carbon and organic matter of soil

Sample	Sand	Silt	Clay	Textural class	Bulk density (g/cm^3)	Organic carbon (%)	Organic matter (%)
PT1-1	54	34	12	Sandy loam	1.14	2.31	4.0
PT1-2	52	35	13	Loam	1.10	1.66	2.9
PT2-1	54	35	11	Sandy loam	1.01	2.53	4.4
PT2-2	51	35	14	Loam	1.04	1.88	3.2
PT3-1	55	35	10	Sandy loam	0.99	2.14	3.7
PT3-2	47	38	15	Loam	1.06	1.44	2.5
Mean	**52.2**	**35.3**	**12.5**	**Sandy loam**	**1.06**	**1.99**	**3.4**

The bulk density of the soil ranged from 0.99 g/cm^3 to 1.14 g/cm^3 with a mean value of 1.06 g/cm^3. The mean bulk densities for top soil and bottom soil were 1.05 g/cm^3 and 1.07 g/cm^3, respectively, meaning that low bulk densities for the top soil. The mean bulk density of 1.06 g/cm^3 was close to 1.0 g/cm^3 observed at the depths of 0-19 cm observed in Romania. The percentage of organic carbon varied from 1.44% to 2.53%. The percentage of organic matter varied from 2.5% to 4.4%.

Sieve Analysis

The percentage passing through different sieve sizes is shown in Figure 6. The results were obtained from three sampling sites with two samples from each site. The percentages passing 0.1 mm sieve were all the same for the three sites. The percentage passing started to differ after 0.2 mm. This difference is very clear for sieve size 1 mm. The highest percentage of 27.59 passing 1 mm sieve was observed in Pit 3 position 1 while the lowest percentage of 10.46 was observed in pit 1 position 1. The same trend was observed in 2 mm sieve where it was found that the highest percentage passing was 41.7 observed in Pit 3 position 1 and the lowest was 25.92 observed in pit 1 position 1. Samples from PT3-1, PT2-2 and PT2-1 had higher passing percentages than the mean while those that were lower than the mean were observed from PT1-1 and PT3-2. Samples from PT1-2 were the same as the mean but became increased after 2 mm sieve.

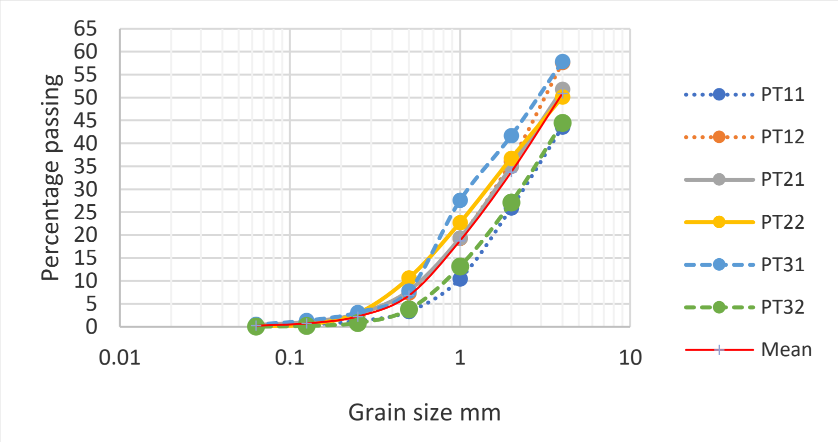

Figure 7: Percentage passing different sieve for soil samples in the study area.

Based on the mean percentage passing, fine sand that was between 0.1 to 0.25 mm was found to be 1.75%. Therefore, the total value for fine sand and silt gives 37.1%.

Saturated Hydraulic Conductivity

The saturated hydraulic conductivity varied from 8.0 µm/s to 41.3 µm/s with a mean value of 24.1 µm/s. There were only two classes high and moderately high translating to between code 2 and 3. Block three under not planting had the highest percent cover (93%) towards the end of the growing season. The highest and lowest rainfall intensities were 31.4 mm/hr and 1.35 mm/hr, respectively with a mean of 16.3 mm/hr. The highest sediment measured was 414 g. Only three invents were more than the mean.

Table 2: Saturated hydraulic conductivity

Sample	**Q(ml)**	**L (cm)**	**H (cm)**	**Area (cm^2)**	**Ksat µm/s**	**Ksat Class**	**Code**
PT1-1	570	4	6	25.52	41.3	High	2
PT1-2	110	4	6	1.10	8.0	Moderately High	3
PT2-1	480	4	6	1.01	34.8	High	2
PT2-2	170	4	6	1.04	12.3	High	2
PT3-1	350	4	6	0.99	25.6	High	2
PT3-2	310	4	6	1.06	22.5	High	2
Mean					**24.1**	**High**	**2**

The saturated hydraulic conductivity varied from 8.0 µm/s to 41.3 µm/s with a mean value of 24.1 µm/s. There were only two classes high and moderately high translating to code 2 and 3, respectively. The smaller the value of hydraulic conductivity, the lower the infiltration rates of water into the soil hence during heavy rains, soil loss will be greater especially in sloping areas.

Percent Cover

Bean crop grown subjected to both mulching and no mulching grew very well during the experiment as shown in Figure 7.

Figure 8: Photos of bean crop – (a) Bean plot with mulching; (b) Bean growing during the study period.

The percent cover for all the treatments in shown in Figure 8. Block 1 had the highest percentage cover for all the treatments from 26 July to 28 August 2019. Block two under no mulch and mulch treatments had the lowest percent cover. Block 2 with no planting had higher percentage cover than those planted. Block 3 had percent cover in between blocks 1 and 2. Block three under not planting had the highest percent (93%) towards the end of the growing season.

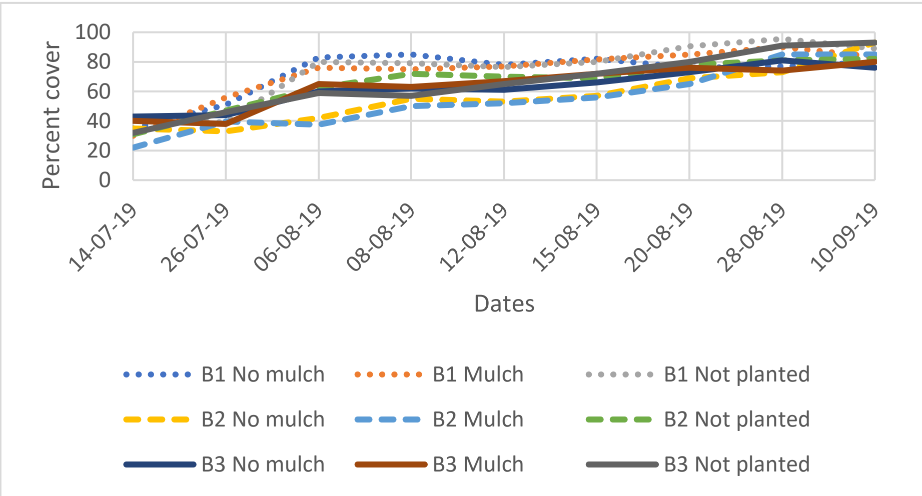

Figure 9: Percentage cover for bean from 14th July - 10th September 2019.

Rainfall Intensities

The rainfall intensities during the research are shown in Figure 9. The highest and lowest rainfall intensities were 31.4 mm/hr and 1.35 mm/hr, respectively with a mean of 16.3 mm/hr. Only three events were more than the mean.

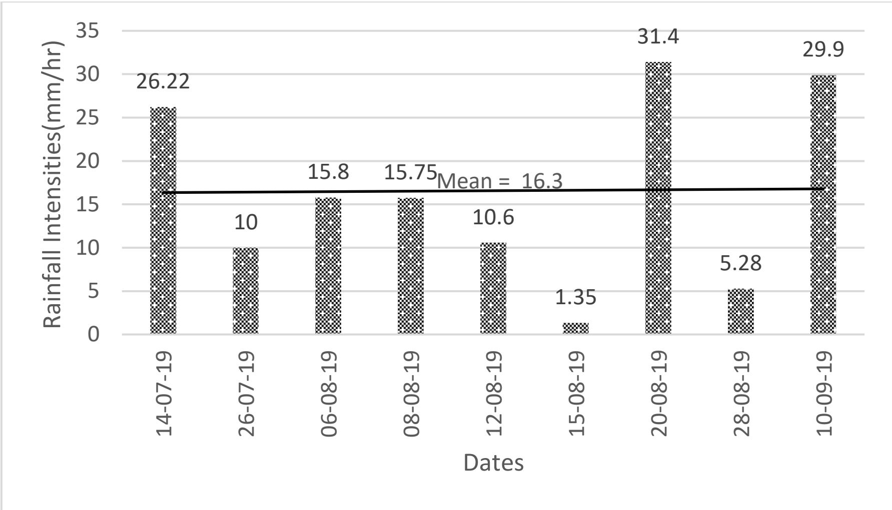

Figure 10: Rainfall intensities at the experimental site.

Table 3: Peak Discharges from Different Plots on Different Dates

Dates	**Maximum peak discharges of run-off (litres/s)**	**Plots where peak was found**	**Measured sediments (g) in order of the plots**	**Maximum sediments (g) on each day**	**Maximum total volume of water (ml)**
14-07-19	0.028	B1T3, B2T3, B3T3	111.2, 274.2, 302	302 (B3T3)	14210 (B3T3)
26-07-19	0.011	B1T3, B2T3, B3T3	2.5, 12.0, 5.3	82.3 (B2T2)	1400 (B2T2)
06-08-19	0.017	B1T3, B2T3, B3T3	0, 1.4, 3.5	14.0 (B2T2)	1750 (B3T3)
08-08-19	0.017	B1T3, B2T3, B3T3	17.7, 37.6, 38.4	398.6 (B3T2)	12950(B3T2)
12-08-19	0.011	B1T3, B2T3, B3T3	0.04, 0.8, 0.2	83.7 (B2T2)	1020(B3T3)
15-08-19	0.001	B1T3, B2T3, B3T3	0,2, 0.02, 0.112	1.14 (B3T2)	710(B3T3)
20-08-19	0.033	B1T3, B2T3, B3T3	0.1, 4.0, 35.6	414 (B3T2)	13720 (B3T2)
28-08-19	0.006	B1T3, B2T3, B3T3	0.52, 0.4, 0.5	3.9(B2T2)	2360 (B3T2)
10-09-19	0.032	B1T3, B2T3, B3T3	2.4, 10.1, 4.4	80.9 (B3T2)	15250(B3T2)

The maximum discharges of run-off occurred in plots that were not planted for all the blocks. The maximum sediments for each day had the highest value of 414 grams observed in block 2 with mulching. This maximum sediment was attributed to maximum volume of water that was harvested from Block 3 treatment 2. This is also the case for what was observed on 10-09-19 where maximum flow of run-off resulted in maximum sediments. The maximum sediments were recorded in the days when maximum total volume of water was recorded. This is the case for 5 out of 9 days when the observation was made. The maximum volume of water was related to peak discharges of run-off for all the plots.

DISCUSSION

Low mean bulk densities of soil are associated with low degree of compaction and consequently means that the soil is loose and can be susceptible to erosion (Moraru, et al., 2020). Low compaction encourages infiltration of water into the soil hence decreased run-off and decreased erosion of soil in sloping areas.

The organic carbon falls within the agricultural soils under grain production that have soil organic carbon of between 0.8-2.0% found at depths of 0-10 cm and have bulk density of 1.0 g/cm^3. It can be noted that organic carbon is 58% of organic matter (agri.wa.gov.au, 2021).

Taking the means, the soil texture is sandy loam (García-Gaines & Frankenstein, 2015). Soil texture is the main characteristic that affects soil erodibility and therefore with sandy loam and loam soil they are expected to be less erodible than silt or very fine sand (Ritter, 2012).

High values of silt and fine sand increases the detachability of soil and hence increased splash erosion. These small particles are hard to aggregate and can easily be transported. Small particles like silt and fine sand are more erodible than large particles because of the difference in inertial and drag forces (Sun, et al., 2021).

Soils samples in PT2-2 had saturated hydraulic conductivity of 12.3 µm/s which is close to the mean of sandy loam soils 13.7 µm/s observed by García-Gutiérrez, et al., 2018 from a sample of size of 2123.

The rainfall intensities were well below the extreme rainfalls of 1200 mm/hr used in some study in China. The soil erosion is therefore expected to be more during high rainfall intensities since soil erosion is directly proportional to raindrops (Sun, et al., 2021).

CONCLUSION AND RECOMMENDATION

The MUSLE model did not perform well when it came to validation. This was associated with the digging of trenches to separate plots which were thought to have resulted in high sediments at first as the ground was disturbed. The model can work perfectly well for rainfall intensities of around 26 mm/hr. Further studies on sediment yield is needed for slopes greater than the one used in the study.

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