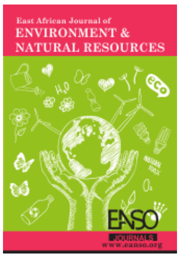


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*Original Article*

# Assessment of Runoff and Soil Loss Under Natural Vegetation Cover and Rainfall in a Semi-Arid Catchment, West Pokot County, Kenya.

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*Soil Erosion, Semi-arid lands, Runoff plot, Sediment, Slope grade.*

**ABSTRACT**

Soil erosion has become a major cause of land degradation with regrettable economic losses. It has affected livelihoods of many agro-pastoral communities in Arid and Semi-arid Lands (ASALs). There is need for continuous assessment of soil erosion in these areas in order to provide sufficient data on soil loss for soil resource management, conservation, and land use planning. The purpose of this study was to determine the rate of soil loss by water for soil conservation planning in West Pokot County, Kenya. Two adjacent fields with variable vegetation cover density were identified in a semi-arid catchment for runoff plot research. Vegetation cover on the fields was measured using the transect line-intercept survey method. Field 1 had 25–50% vegetation cover while field 2 had 50–75% vegetation cover. On each field, three identical erosion plots with dimensions 20 m along the slope and 10 m wide were constructed. Runoff and sediment from the plots were measured for fifteen rainfall-runoff events during the long rains season. Data was analysed using correlation analysis and linear regression methods. The results show that runoff production varied from 1.03% to 1.44% of total rain water. Soil loss from the plots was 120.3–155.5 $g/m^2$. Runoff-rainfall correlation analysis showed a significant positive relationship (r =0.9609, P<0.05%) with 92.33% variance in runoff production. Soil loss had significant positive relationship with runoff (r =0.9840, P<0.05%) with 96.83% variance in soil loss. The study found that runoff production and soil loss was slow in the field with dense vegetation cover. Studies project an increase in human and livestock populations in semi-arid areas. This points at possible decrease in vegetation cover and increase in the rate of soil loss by water. The study recommends development of a soil conservation and management strategy in the study area.

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## INTRODUCTION

Soil erosion has significant on-site and off-site impacts. It is a dominant agent of land degradation accounting for 70 to 90 percent of total soil loss in the world (Tesfahunegn *et al*., 2013). In China, India, and Northern Ethiopia, high rate of soil erosion has been reported (Kayet *et al*., 2018; Tadesse *et al*., 2017; Gelagay & Minale, 2016; Guo *et al*., 2015). According to FAO/UNEP approximations, soil erosion had already affected more than two billion hectares of land in the world by the year 2014. The typical rate of global soil loss from these approximations was almost 9 million ha/yr. Loss of nutrients and organic carbon from the soil leads to reduction in soil productivity and its ability to sustain life (Martinez-Mena *et al*., 2019). It is estimated that the yield reduction due to soil erosion range from 2 to 40 percent in Africa because the soil depth is diminished by 1 mm following a loss of 15 tons of soil from a hectare piece of land in a single storm (Alam, 2014). A study on soil erosion in Kenya shows that upper River Mara catchment loses soil at the rate of 29.95–162.38 g/m$^2$/yr (Defersha & Melesse, 2012). This translates to about 0.3–1.6 tons /ha/yr. erosion rate.

Soil erosion by water is most widespread and serious (Ghabbour *et al*., 2017). This is the worst form of soil destruction with serious environmental and socio-economic implications (Phinzi & Ngetar, 2019). It results from complex hydro-geomorphic interactions on slopes. Rainfall, runoff, soil characteristics, terrain, and land cover are factors which influence water erosion (Kayet *et al*., 2018). Runoff and soil loss have significant positive relationship (Abua & Digha, 2015). The hydraulic force of runoff cause detachment of soil particles and its flow on the slope facilitates translocation of the detached soil particles to different locations in the lowlands. High intensity rainfall is often associated with high amount of runoff and higher rate of soil loss (Mohamadi & Kavian, 2015).

Water erosion has caused serious problems in the Arid and Semi-arid Lands (ASALs) which has affected community livelihoods and soil conservation effort (Konana *et al*., 2017). In Kenya, destruction of vegetation cover which exposes the soil to erosion is caused by uncontrolled human activities from their up-surging populations (Olang & Furst, 2010). Studies show that 84% of Kenya is ASALs and is a home of 30% human population with at least 70% of the national livestock herd (GoK, 2012). The implication of this situation on such fragile environment is overgrazing and deforestation. This is a clear indication that these areas are at risk of high rate of soil erosion by water given that soils in ASALs are highly erodible (GoK, 2016a).

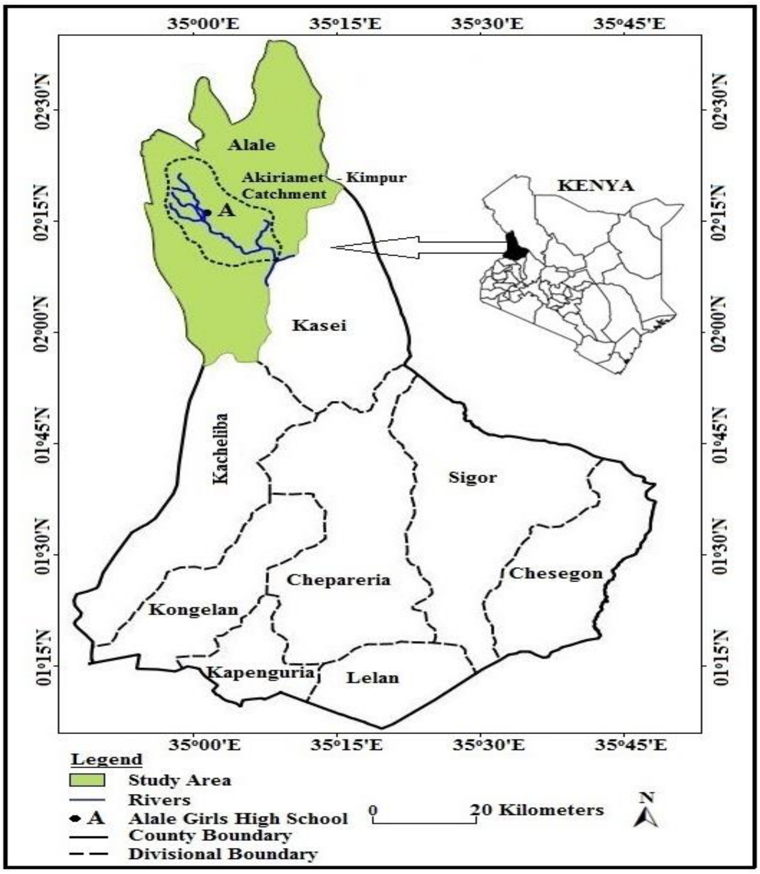
Soil erosion facilitates movement of sediment and agrochemicals from farmlands to valley bottoms where siltation in riverbeds can cause flooding and contamination of water resources in the lowlands. Sediment problem results to huge economic costs (Morgan, 2005). Therefore, there is urgent need to prioritize protection of soil resources by finding practical solutions to this problem before the world falls into catastrophic losses in terms of agricultural yields and critical ecosystem malfunction. The best way to maintain healthy soil is preventing soil erosion through education, advocacy, and concrete actions in the field (FAO, 2019). This calls for an audit into the status of soil erosion in various parts of our countries. Continuous assessment and quantification of soil erosion rates at catchment level is key to providing sufficient information on the extent of soil loss. Erosion plot studies have been used for this purpose. In addition, data from erosion plot studies form a database from which models for calculating and predicting soil erosion rates can be developed. For instance, the Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) were developed on the basis of field plot data collected over long period of time in the United States (Guo *et al*., 2015). This study sought to assess the status of soil loss by water in a semi-arid catchment for the purpose soil resource management and conservation planning. Quantities of sediment in runoff from erosion plots were measured under natural rainfall and vegetation cover characteristics in Akiriamet-Kimpur catchment in West Pokot County, Kenya.

## MATERIALS AND METHODS

### Site Description

The study site (*Figure 1*) is located at (2° 27' N, 35° 22' E), approximately 1600 m above sea level on gentle slopes of 1.5–2.0% slope grade in West Pokot County, Kenya. West Pokot County is 80% semi-arid (GoK, 2016b). It has two major physiographic regions: Dry semi-arid lowlands at 500–1600 m above sea level and sub-humid highlands at 1700–3300 m above sea level. Topographic and climatic characteristics of the study site reflect semi-arid conditions. Annual rainfall is bimodal and varies from 600 mm to 900 mm. The mean monthly temperature reach over 30 °C . Dominant soil type is clay-sandy soils. The soil depth is shallow where partly weathered rocks form closer to the surface. Common types of vegetation include dwarf shrubs, thorny bushes of short acacia trees, euphorbia plants, and desert grass species (*Figure 2*).

**Figure 1: Location of study site in Kenya**




Source: Topographic Sheet for Moroto (NA-36-8) and National Atlas of Kenya.

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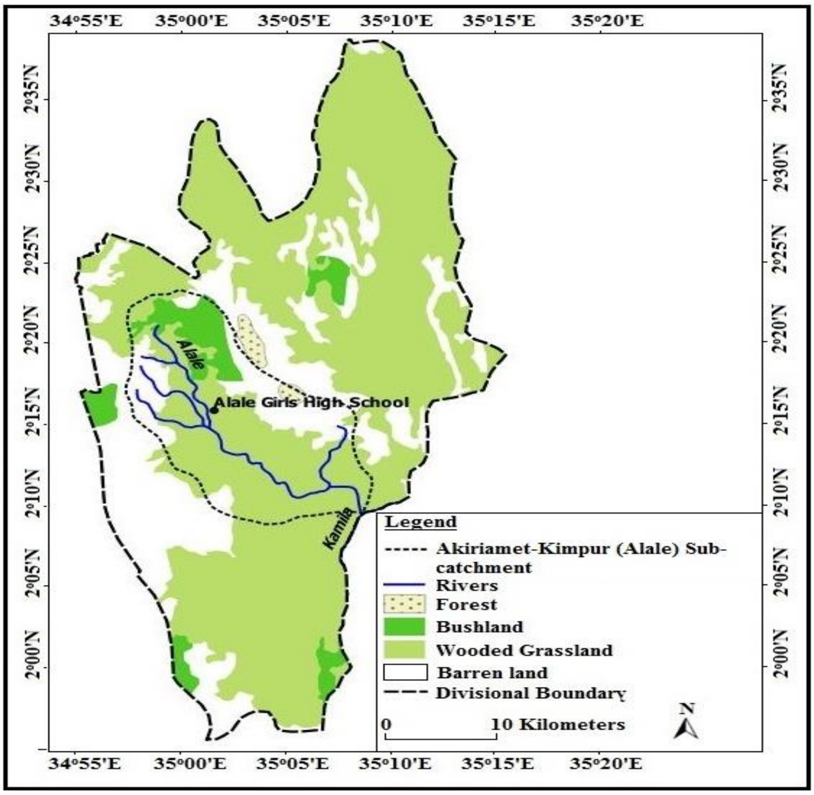
**Figure 2: Vegetation distribution in the study site**




Source: World Resources Institute. <https://www.wri.org/data/kenya-gis-data#other

## Research Methodology

Erosion plots and the rain gauge were set up in Akiriamet-Kimpur catchment. Observations on runoff and sediment eroded from the plots were made over a period of four months during the long rains season.

The slope grade ($\mu\%$) was established using equation (1).

$\mu\% = [\frac{Rise}{Run}] \times 100$ (Barcelona Field studies Centre, 2000) [1]

Where; *Rise* refers to change in altitude between two points on the slope, *Run* refers to length along the slope surface between the two points, The rise and the run were measured at randomly selected points on the slope surface using a tape measure, a piece of rope, a set square, and surveying rods. The slope angle (θ°) was worked out using equation (2).

$\theta° = \tan^{-1}\left(\frac{\text{Rise}}{\text{Horizontal distance between the two points}}\right)$ [2]

Table 1 shows a summary of slope measurements in the fields during the study.

**Table 1: Summary of slope measurements**

| | Plot | Slope Length (Run) | Altitudinal Rise (Rise) | Horizontal Difference | Slope Grade ($[\frac{Rise}{Run}]$ x100%) | Slope Angle (θ°) |
|---|---|---|---|---|---|---|
| Field 1 | A | 20 m | 0.32 m | 19.9 m | 1.6% | 0.92° |
| | $A_1$ | 20 m | 0.36 m | 19.8 m | 1.8% | 1.04° |
| | $A_2$ | 20 m | 0.34 m | 19.8 m | 1.7% | 0.98° |
| Field 2 | B | 20 m | 0.30 m | 19.9 m | 1.5% | 0.86° |
| | $B_1$ | 20 m | 0.38 m | 19.7 m | 1.9% | 1.11° |
| | $B_2$ | 20 m | 0.32 m | 19.9 m | 1.6% | 0.92° |

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Units of vegetation cover were then established using transects line-intercept survey method (Coulloudon *et al*., 1999). A base line transect was laid at random through vegetation field. Subsequent transects were laid parallel to the baseline transect at sufficiently small regular intervals. Percentage vegetation cover (*P*) on the soil along each transect line was computed using equation (3).

$$P = \left(\frac{d_1 + d_2 + \cdots}{l} \times 100\right) \quad [3]$$

Where; *d* refers to the length on the transect line intercepted by tree canopies and shrubs, *l* refers to the total length of the transect line including bare grounds

However, the length (*l*) excluded areas under grasses away from the canopies of taller plants. Grass cover on the soil was estimated by demarcating the area into convenient regular geometrical shapes and calculated as percentage area of the field using available mathematical formulae. Percentage vegetation cover on the field was taken as the mean percentage plant canopy cover for all transects plus percentage grass cover on the soil. The runoff plots were then demarcated and constructed.

Vegetation cover was measured at the beginning of observations in March. The second and the third measurements were taken in May and July respectively because of expected canopy cover development on the fields during the research period (*Table 2*).

**Table 2: Vegetation covers on each field by plant type in March, May, and July**

| **Plant types** | **Percentage cover on the soil in relation to the total area of the field** | | | | | |
|---|---|---|---|---|---|---|
| | **March** | | **May** | | **July** | |
| | **Field 1** | **Field 2** | **Field 1** | **Field 2** | **Field 1** | **Field 2** |
| Euphorbia plants | 5 | 3 | 6 | 3 | 6 | 4 |
| Short acacia tree bushes | 12 | 9 | 14 | 12 | 20 | 16 |
| Grasses | 8 | 16 | 15 | 21 | 23 | 27 |
| Shrubs | 0 | 22 | 0 | 26 | 0 | 28 |
| Percentage total | 25 | 50 | 35 | 62 | 49 | 75 |

**Design of the Erosion Plots**

The sides of each plot were bounded by concrete walls 0.45 m high. The foundation was at least 0.15 m deep to keep off unwanted runoff. A gutter was connected to the lower end of each plot in order to direct runoff and sediment from the plot to collection tanks at the base (*Figure 3* & *Plate 1*).

Six cubical metallic tanks of volume 0.125 $m^3$ each were used to collect runoff from the plots. Each runoff collection tank with a lid was kept in a sub-surface open tank constructed at the base of each plot. The sub-surface open tanks were plastered with water-proof cement component and covered by an iron sheet to keep off direct rainfall and any water loss through infiltration and evaporation processes. They were also used to trap overflow runoff and sediment. The volume of runoff collected in the runoff collection tanks was mathematically computed. The height of runoff in the tanks was measured using a tape measure and multiplied by the base area of the tank. Sediment in the runoff was allowed to decant and then runoff poured away. The sediment was dried and measured using a weighing scale. A standard rain gauge sunk 0.15 m in the ground was installed in the neighbourhood of the plots on a relatively flat ground surface at least 10 m by radius away from taller plants. The funnel was kept 0.3 m above the surface (Plate 2). Water collected in the water collection jar of the rain gauge was transferred to a measuring cylinder with World Meteorological Organization (WMO) specifications for measuring rainfall in tropical regions.

 

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**Figure 3: Schematic design of the runoff plots used in the study**

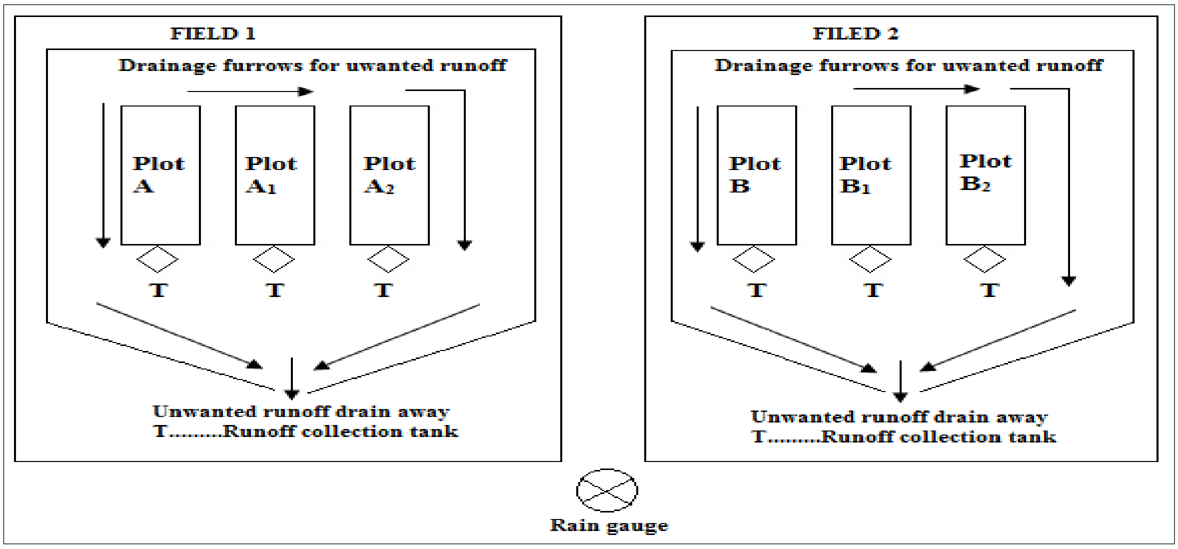


**Plate 1: An erosion plot used in the study**

**Plate 2: Rain gauge used in the study**

**Data Analysis**

A total 372.7 mm of rainfall in the catchment area produced 2.104 $m^3$ of runoff from the plots. This represents 1.03–1.44% of total rain water lost through runoff. Similarly, 55.17 kg of soil was lost from plots. Resultant rainfall (x) and runoff (y) values were treated to correlation analysis using Pearson product moment correlation function. The results show that product moment correlation coefficient (r) for rainfall and runoff is 0.9609. The percentage variance ($r^2$) in runoff production is 92.33%, P< 0.05. The level of significance in this association was tested using equation (4) at 5% significance level.

$$t = r\sqrt{\frac{n-2}{1-r^2}}, \text{ (Lucey, 2002)} \qquad [4]$$

$$t = 0.9609 \times \sqrt{\frac{15-2}{1-0.9609^2}} \qquad t = 12.5122$$

Equation (4) is a t-test formula. The critical value of (t) for two-tailed *t*-test distribution at 0.05 significance level and degree of freedom (n - 2) =13 for n = 15 is 2.160 (Dougherty, 2002). The critical value of (t) is less than the derived value. In accordance with the interpretation provided by Dougherty, there exists a significant positive linear relationship between runoff and rainfall. The linear equation; y = **b**x + **a** connecting the runoff component to the rainfall component was worked out using the least square method of linear regression analysis. The values of constants (**b**) and (**a**) were worked out using equation (5) and equation (6) respectively.

 

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$$\mathbf{b} = \frac{n\,(\sum xy) - (\sum x)\,(\sum y)}{n\,(\sum x^2) - (\sum x)^2} \quad [5]$$

**b** = 0.007

$$a = \sum y/_n - b(\sum x/_n) \quad [6]$$

**a** = – 0.035

The derived linear equation from this analysis is y = 0.007x –0.035 (Figure 4).

Similarly, runoff (x) and soil loss (y) values were run through Pearson product moment correlation function. The results show that product moment correlation coefficient (r) for runoff and soil loss is 0.9840. The percentage variance ($r^2$) in sediment generation is 96.83%, P< 0.05. The level of significance in this association was tested using the *t*-test formula at 5% significance level.

$$t = r\sqrt{\frac{n-2}{1-r^2}} \; ; \quad n = 15$$

$$t = 0.9840 \times \sqrt{\frac{15-2}{1-0.9840^2}}$$

$$t = 19.8332$$

The critical value for two-tailed t-test distribution is 2.160 at 0.05 significance level. The critical value is less than the t-value derived. Hence, there exists a significant positive linear relationship between soil loss and runoff. Linear regression analysis for soil loss (y) and runoff (x) was performed using the least square regression method. The resultant linear equation; y = **b**x + **a**, where (**a**) and (**b**) are constants is worked out. The value of (**b**) and (**a**) were computed accordingly.

$$\mathbf{b} = \frac{n\,(\sum xy) - (\sum x)\,(\sum y)}{n\,(\sum x^2) - (\sum x)^2} = 30.67$$

$$\mathbf{a} = \sum y/_n - b\,(\sum x/_n) = -0.624$$

The derived linear equation from this analysis is y = 30.67x − 0.624 (*Figure 5*).

**Figure 4: Derived runoff-rainfall linear relationship**

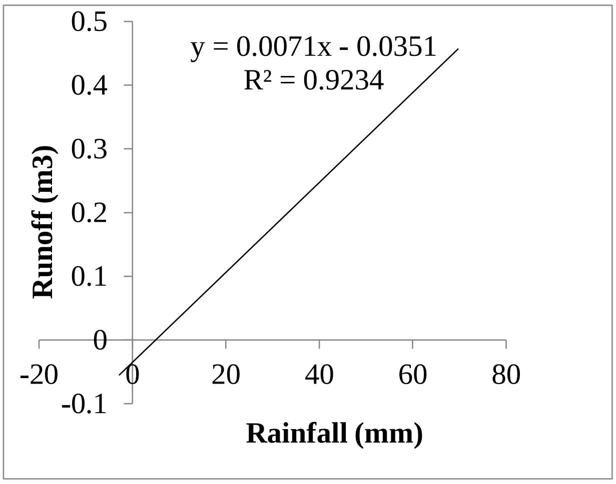
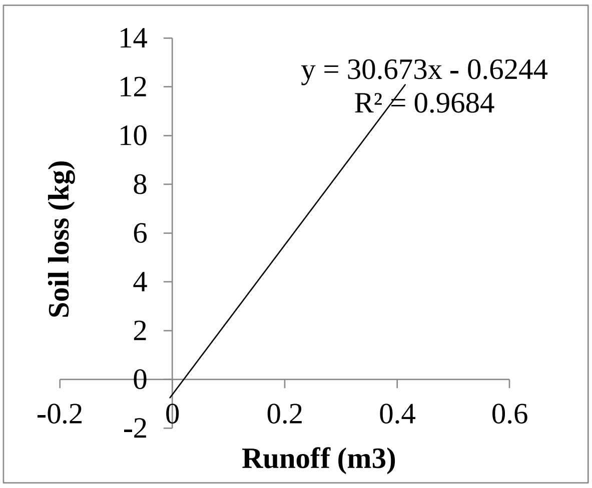



**Figure 5: Derived soil loss-runoff linear relationship**




## RESULTS AND DISCUSSION

Thirty rainfall events were observed out of which fifteen were erosive. Raw data from event-based observations and a summary of measured rainfall, runoff and soil loss values are presented in *Table 3* and *Table 4*.

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**Table 3: Rainfall, runoff, and soil loss values from erosive rainfall-runoff events**

| DD | Rn | Fd 1 | Rf | SY | Fd 2 | Rf | SY | DD | Rn | Fd 1 | Rf) | SY | Fd 2 | Rf | Sy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26/3/17 75 mins | 45.0 | A | 0.1550 | 4.22 | B | 0.1375 | 3.56 | 16/6/17 30 mins | 15.8 | A | 0.0700 | 1.12 | B | 0.0125 | 0.58 |
| | | $A_1$ | 0.1450 | 3.71 | $B_1$ | 0.1250 | 3.43 | | | $A_1$ | 0.0800 | 1.38 | $B_1$ | 0.0375 | 0.80 |
| | | $A_2$ | 0.1500 | 3.53 | $B_2$ | 0.1450 | 3.51 | | | $A_2$ | 0.0150 | 0.05 | $B_2$ | 0.0050 | 0.12 |
| | | Mean | 0.1500 | 3.82 | Mean | 0.1358 | 3.50 | | | Mean | 0.0483 | 0.85 | Mean | 0.0183 | 0.50 |
| 17/4/17 79 mins | 28.5 | A | 0.1100 | 3.60 | B | 0.1025 | 2.88 | 04/7/17 36 mins | 12.0 | A | 0.0125 | 0.26 | B | 0.0050 | 0.32 |
| | | $A_1$ | 0.1075 | 3.20 | $B_1$ | 0.0900 | 2.41 | | | $A_1$ | 0.0100 | 0.22 | $B_1$ | 0.0025 | 0.13 |
| | | $A_2$ | 0.1000 | 3.10 | $B_2$ | 0.0700 | 2.15 | | | $A_2$ | 0.0125 | 0.24 | $B_2$ | 0.0000 | 0.00 |
| | | Mean | 0.1058 | 3.30 | Mean | 0.0875 | 2.48 | | | Mean | 0.0117 | 0.24 | Mean | 0.0025 | 0.15 |
| 29/4/17 35 mins | 8.2 | A | 0.0310 | 0.95 | B | 0.0275 | 0.51 | 05/7/17 32 mins | 21.0 | A | 0.0450 | 1.19 | B | 0.0300 | 0.71 |
| | | $A_1$ | 0.0290 | 0.58 | $B_1$ | 0.0250 | 0.34 | | | $A_1$ | 0.0500 | 1.33 | $B_1$ | 0.0325 | 0.81 |
| | | $A_{23}$ | 0.0300 | 0.75 | $B_2$ | 0.0290 | 0.65 | | | $A_2$ | 0.0550 | 1.38 | $B_2$ | 0.0375 | 0.91 |
| | | Mean | 0.0300 | 0.76 | Mean | 0.0272 | 0.50 | | | Mean | 0.0500 | 1.30 | Mean | 0.0333 | 0.81 |
| 30/4/17 64 mins | 30.1 | A | 0.1250 | 2.74 | B | 0.0875 | 2.55 | 21/7/17 25 mins | 7.2 | A | 0.0025 | 0.15 | B | 0.0025 | 0.14 |
| | | $A_1$ | 0.1225 | 2.73 | $B_1$ | 0.1000 | 2.80 | | | $A_1$ | 0.0050 | 0.31 | $B_1$ | 0.0025 | 0.16 |
| | | $A_2$ | 0.1200 | 2.45 | $B_2$ | 0.0725 | 2.15 | | | $A_2$ | 0.0050 | 0.08 | $B_2$ | 0.0000 | 0.00 |
| | | Mean | 0.1225 | 2.64 | Mean | 0.0867 | 2.50 | | | Mean | 0.0042 | 0.18 | Mean | 0.0017 | 0.10 |

 

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| DD | Rn | Fd 1 | Rf | SY | Fd 2 | Rf | SY | DD | Rn | Fd 1 | Rf) | SY | Fd 2 | Rf | Sy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/5/17 55 mins | 34.3 | A | 0.1325 | 2.51 | B | 0.0725 | 2.30 | 22/7/17 15 mins | 7.8 | A | 0.0100 | 0.20 | B | 0.0100 | 0.25 |
| | | $A_1$ | 0.1450 | 2.80 | $B_1$ | 0.0700 | 2.57 | | | $A_1$ | 0.0075 | 0.12 | $B_1$ | 0.0050 | 0.07 |
| | | $A_2$ | 0.1250 | 2.19 | $B_2$ | 0.0675 | 1.88 | | | $A_2$ | 0.0175 | 0.28 | $B_2$ | 0.0025 | 0.04 |
| | | Mean | 0.1342 | 2.50 | Mean | 0.0700 | 2.25 | | | Mean | 0.0117 | 0.20 | Mean | 0.0058 | 0.12 |
| 19/5/17 106mins | 69.7 | A | 0.2450 | 7.90 | B | 0.2250 | 5.82 | 24/7/17 27 mins | 16.6 | A | 0.0250 | 0.37 | B | 0.0100 | 0.18 |
| | | $A_1$ | 0.2000 | 7.65 | $B_1$ | 0.2000 | 5.59 | | | $A_1$ | 0.0400 | 0.71 | $B_1$ | 0.0125 | 0.13 |
| | | $A_2$ | 0.1735 | 6.95 | $B_2$ | 0.1700 | 5.27 | | | $A_2$ | 0.0575 | 0.87 | $B_2$ | 0.0250 | 0.29 |
| | | Mean | 0.2062 | 7.50 | Mean | 0.1983 | 5.56 | | | Mean | 0.0408 | 0.65 | Mean | 0.0158 | 0.20 |
| 30/5/17 84 mins | 40.5 | A | 0.2100 | 5.52 | B | 0.1150 | 4.15 | 25/7/17 36 mins | 18.2 | A | 0.1050 | 0.96 | B | 0.0275 | 0.31 |
| | | $A_1$ | 0.1875 | 5.27 | $B_1$ | 0.1575 | 4.77 | | | $A_1$ | 0.0575 | 0.52 | $B_1$ | 0.0225 | 0.23 |
| | | $A_2$ | 0.1750 | 5.11 | $B_2$ | 0.1750 | 4.88 | | | $A_2$ | 0.0500 | 0.38 | $B_2$ | 0.0125 | 0.09 |
| | | Mean | 0.1908 | 5.30 | Mean | 0.1492 | 4.60 | | | Mean | 0.0708 | 0.62 | Mean | 0.0208 | 0.21 |
| 31/5/17 28 mins | 17.8 | A | 0.0625 | 1.58 | B | 0.0300 | 0.79 | Total | 372.7 mm | | 1.2270 | 31.11 | | 0.8770 | 24.06 |
| | | $A_1$ | 0.0475 | 1.20 | $B_1$ | 0.0275 | 0.73 | | | | | | | | |
| | | $A_2$ | 0.0400 | 0.97 | $B_2$ | 0.0150 | 0.22 | | | | | | | | |
| | | Mean | 0.0500 | 1.25 | Mean | 0.0241 | 0.58 | | | | | | | | |

***Key: DD = Date & duration; Rn = Rainfall (mm); Fd = Field; Rf = Runoff (m3); SY = Sediment yield (kg)***

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**Table 4: Summary of observed rainfall, runoff, and soil loss**

| **Rainfall event** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rainfall (mm)** | | 45.0 | 28.5 | 8.2 | 30.1 | 34.3 | 69.7 | 40.5 | 17.8 | 15.8 | 12.0 | 21.0 | 7.2 | 7.8 | 16.6 | 18.2 |
| **Field 1** | Runoff ($m^3$) | 0.150 | 0.106 | 0.030 | 0.123 | 0.134 | 0.206 | 0.191 | 0.050 | 0.048 | 0.012 | 0.050 | 0.004 | 0.012 | 0.041 | 0.071 |
| | Soil loss (kg) | 3.82 | 3.30 | 0.76 | 2.64 | 2.50 | 7.50 | 5.30 | 1.25 | 0.85 | 0.24 | 1.30 | 0.18 | 0.20 | 0.65 | 0.62 |
| **Field 2** | Runoff ($m^3$) | 0.136 | 0.087 | 0.027 | 0.086 | 0.070 | 0.198 | 0.149 | 0.024 | 0.018 | 0.002 | 0.033 | 0.002 | 0.006 | 0.016 | 0.021 |
| | Soil loss (kg) | 3.50 | 2.48 | 0.50 | 2.50 | 2.25 | 5.56 | 4.60 | 0.58 | 0.50 | 0.15 | 0.81 | 0.10 | 0.12 | 0.20 | 0.21 |
| **Total runoff *($m^3$)*** | | 0.286 | 0.193 | 0.057 | 0.209 | 0.204 | 0.404 | 0.340 | 0.074 | 0.066 | 0.014 | 0.083 | 0.006 | 0.018 | 0.057 | 0.092 |
| **Total soil loss (kg)** | | 7.32 | 5.78 | 1.26 | 5.14 | 4.75 | 13.06 | 9.90 | 1.83 | 1.35 | 0.39 | 2.11 | 0.28 | 0.32 | 0.85 | 0.83 |

**Runoff Production in the Catchment**

Runoff production was higher in field 1 than in field 2 (Figure 6 & 7). The findings show that the coefficients of runoff production were 1.44% and 1.03% in field 1 and 2 respectively. This means that runoff production dropped by 29% in field 2. Since a negative relationship exists between runoff and vegetation cover (Green *et al*., 1994), lower runoff production in field 2 was due to denser vegetation cover. At the start of observations, total runoff from both plots was significantly high (1.7683 $m^3$ in March, April, and May). However, in June and July, it dropped remarkably to 0.3357 $m^3$. This can be explained in two ways: First, vegetation cover on the fields at the onset of rains was low perhaps due to effects of the preceding dry season where plants withered or got destroyed by livestock. Interception of the raindrops by plant canopies in this case was low leading to production of higher runoff. A drop of 29% in runoff production in field 2 confirms the important role of vegetation cover in controlling runoff production (Jia *et al*., 2020; Bochet *et al*., 2006).

Secondly, partially weathered rock layers occur closer to the surface of the soil in the catchment. Surface crusting is widespread in ASALs and may be the primary reason for low infiltration of water in the soil. Surface crusting may be caused by large herds of livestock. The characteristics of the ASAL soils cause decrease in infiltration rate of water in the soil causing production of higher runoff. Generally, the amount of runoff produced on a slope depends on amount of rainfall, changing surface vegetation cover and antecedent moisture in the soil.

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**Implication of Higher Runoff Generation from the Slopes of the Study Area**

There is possibility of losing large volume of runoff water if there are no sufficient mechanisms of tapping and using it. The study found that over 43,800 litres/ha/year of total rain water is lost through runoff in the catchment. Access to adequate water is a serious problem in the ASALs. This water can be harvested and put to use. Hydrological studies on the possibilities of harvesting, using, and conserving this water should be considered.

Possibility of flash floods in the lower course of Akiriamet-Kimpur ephemeral drainage system is high. This would interfere with transport services, destroy property, and claim lives of people and livestock.

***Sediment Generation and Soil Loss in the Catchment***

Analysis of soil loss from the plots shows that soil loss was higher in field 1 where 56% of total soil loss occurred (Figure 8 & 9). However, it decreased by 23% in field 2. This observation is attributed to denser vegetation cover in field 2. It is already noted that denser vegetation cover slows down production of runoff. Since correlation analysis of runoff and rainfall data from this study shows a strong positive relationship, it means that dense vegetation cover is associated with reduced rate of sediment generation. In addition, vegetation through plant rooting system provides firm grasp on the soil particles to further reduce their erodibility.

**Figure 6: Daily runoff totals from each plot**

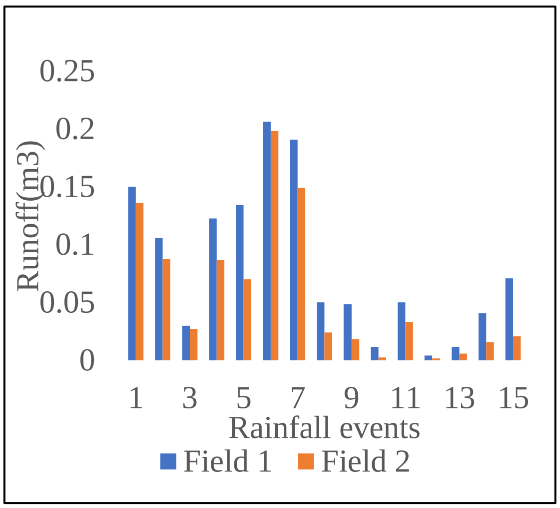


**Figure 7: Monthly runoff totals from each plot**

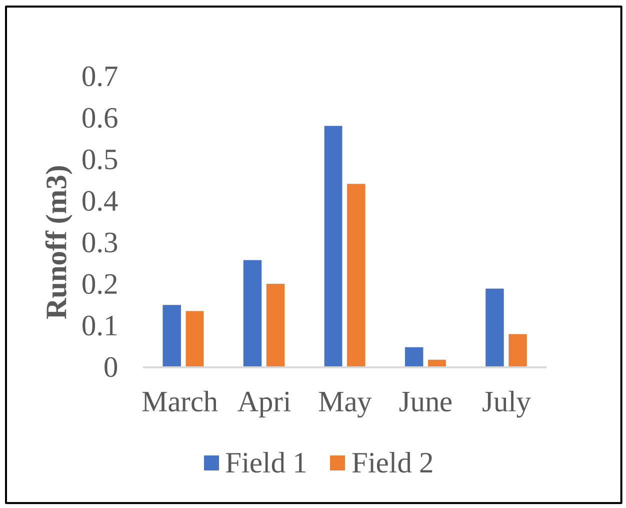


 

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**Figure 8: Daily soil loss totals from each plot**

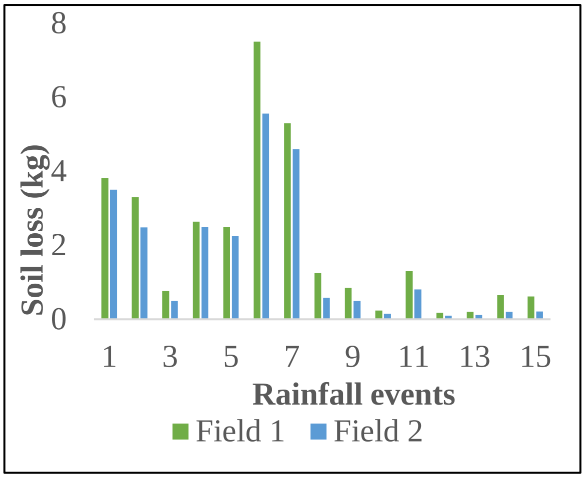
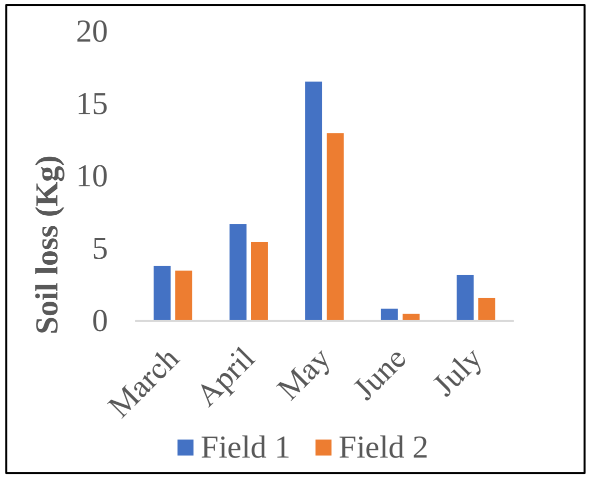



**Figure 9: Monthly soil loss totals from each plot**




Runoff and soil loss values in the study show a similar trend over the observed rainfalls. The study established a significant positive relationship between soil loss and runoff production ($r = 0.9840$, $P < 0.05$). This means that a larger quantity of sediment is expected in resultant runoff when higher amounts of runoff are produced from the slopes of the catchment area.

High intensity rainfall is associated with high amount of runoff and higher rate of soil loss (Mohamedi & Kavian, 2015). It is important to observe that while the trend in sediment generation is similar to the trend in runoff production over the observed rainfalls, the trend in runoff production is also similar to the trend in rainfall amounts over the same rainfall events. In essence, rainfall, runoff, and soil loss observations in this study show similar trends over observed rainfalls. This means that rainfall, runoff, and soil loss have a positive relationship (Abua & Digha, 2015). There was notable decrease in both runoff and soil loss from the eighth to the fifteenth rainfall events. This is because canopy cover developed by dry land plants is a natural cushion against the energy impact of rainfall hence promotes infiltration of rain water and controls runoff and sediment production (Vasquez-Mendez *et al*., 2010). The study establishes that this decrease was caused by progressive development in vegetation cover on the soil in the plots.

The analysis shows that the rate of soil loss by water in the catchment is 120.3–155.5 g/m$^2$. It means that a minimum of 1.203 tonnes of soil is lost per hectare every year through runoff. The following conditions had significant influence on the rate of soil loss in the catchment.

- Bare soil surface exposed to direct sunlight and direct rain drops. Direct sunlight cause increase in evaporation of moisture from the soil which loosens the soil particles. Unconsolidated soil particles are vulnerable to erosion. Direct raindrops mechanically cause detachment of the soil particles through splash erosion.
- Large herds of livestock trample on the soil as they graze. Thus, the soil particles become loose and vulnerable to erosion.
- Insufficient plant rooting systems due to sparse vegetation which would provide anchorage to the soil particles. The soil particles in this case are erodible even in the event of the least hydraulic force in runoff.
- High rainfall intensity which caused excessive Hortonian and saturation overland flow.

***Implication of Large Sediment Generation from the Slopes of the Study Area***

Sediment production and movement from the hill slopes to valley bottoms can influence agriculture negatively. Top fertile soil is moved down the slope causing land degradation on the slopes. Siltation in the valley bottoms especially on the ephemeral river beds cause reduction in the depth of river channels.

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This situation is likely to cause floods. Furthermore, occurrence of gullies on the slope surface may cause development of a rugged terrain. Gully development is a direct effect of soil erosion on slope surfaces.

## CONCLUSION

A least 43,850 litres of runoff and 1.203 tons of soil are lost from slopes of the study area per hectare every year. A significant positive relationship exists between runoff and soil loss. This implies that any effort to mitigate soil erosion by water should start with controlling runoff production. In relation to vegetation cover, the study found a negative relationship between runoff production and vegetation cover. Up-surging human and livestock populations in ASALs threaten improvement in vegetation cover on land which certainly puts the soils at risk of erosion. It points at possible increase in the rate of soil erosion by water in the study area from the minimum rate reported in this paper. Soil conservation and management policies should prioritize protection of dry land vegetation because it is a natural shield against soil erosion in these parts of the world.

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