# INFLUENCE OF LAND USE LAND COVER CHANGES ON SOIL EROSION IN ELGEYO ESCARPMENT, KENYA

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## ABSTRACT

Land use land cover changes (LULC) are known to cause land degradation in various forms including soil erosion. The Elgeyo Escarpment is within the Kenya's Rift Valley, a mountainous section with rugged terrain and receives fairly high rainfall. These factors, coupled with unsustainable LULC changes, make the escarpment prone to soil erosion challenges. Despite this vulnerability, information on soil loss is scanty. This paper evaluates the impact of LULC changes on soil erosion occurrence in the Elgeyo Escarpment between 1995 and 2020. Revised Universal Soil Loss Equation model, remote sensing and ground truths were used. The results revealed that the average intolerable soil erosion rates were 14.0 t/ha/yr and 18.76 t/ha/yr in 1995 and 2020, respectively. Scrubland, cropland, grassland, forest and built-up areas contributed 67.1%, 20.1%, 7.8%, 4.8% and 0.2%, respectively of the total soil loss in 1995. By 2020, the contributions of shrubland and forest to erosion had dramatically declined to 39.8% and increased to 39.4%, respectively. Cropland, shrub/grassland and built-up areas contributed 20.2%, 0.3% and 0.3%, respectively. The highest rates of soil erosion occurred in built-up areas converted from shrub/grassland (1.04 t/ha) followed by cropland converted from forest (0.59 t/ha). Soil erosion rate increased with increased slope angle owing to high velocity and runoff erosivity, with areas having slope >30$^0$ experiencing the highest rate (1225 t/ha/y). Therefore, there is need to review land use and soil conservation practices to ensure sustainable management of the escarpment.

**Keywords:** soil erosion, erodibility, erosivity, RUSLE, Elgeyo escarpment, land use land cover

## INTRODUCTION

Land use land cover change (LULC) has been identified as one of the main factors that lead to degradation of many terrestrial ecosystems in the past half millennium (Kindu *et al.*, 2015). In eastern Africa, a notable decrease in pasture land has been attributed to overstocking between 1992 and 1999 (Lambin *et al.*, 2003).

Kenya has continued to experience notable and varied LULC changes over the last three decades with a significant loss of agricultural land to urban area between 1984 to 2013 in Kiambu (Musa *et al.*, 2015). There has also been a remarkable increase in built-up, agricultural areas and reduction in forestland, and grassland between 1995 and 2017 in western Kenya (Kogo *et al.*, 2021). Similar LULC trends were observed in Elgeyo Marakwet County where the changes took place in fragile areas such as Rimoi National Reserve (Togoch, 2018) and the Elgeyo Escarpment (Kilimo, 2014). These changes have been driven by a number of factors such as population growth, urbanization and global market forces. Unfortunately, most of these LULC changes happen even in unsuitable ecologies impacting negatively on the natural environment. In Ethiopia, an evaluation of soil characteristics among four LULC classes revealed that forest land had favourable soil properties followed by homestead gardens, while the least favourable soil properties were found in intensively cultivated outfields. Therefore, increase in the extent of cultivated land at the expense of forest cover associated with poor management promoted significant loss of soil quality in intensively cultivated outfields (Bufebo *et al.*, 2020).

The highlands in the great Rift Valley where Elgeyo Escarpment is found are susceptible to soil erosion

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because of its rugged terrain (Haregeweyn *et al.*, 2017). This is worsened by the unsustainable land management practices in the area that include deforestation and cultivation on steep slopes (Kogo *et al.*, 2021). The rate of soil erosion increases with increase in slope angle due to high velocity of the runoff and erosivity of the rainfall with areas having high erodibility in the region being found primarily in slopes of more than $30^0$, especially in Mt. Elgon, Cherang'any Hills and Elgeyo Escarpments (Kogo *et al.*, 2020). Evidently, soil erosion is taking place in the Elgeyo Escarpment as indicated by the decline in farm productivity, low nutrients levels and occurrence of sediments in river water flowing downstream across the escarpment (Wiborgh, 2015). This paper therefore assesses the influence of LULC changes on the occurrence, spatial distribution, quantities and rates of soil loss in the Elgeyo Escarpment.

## MATERIALS AND METHODS

### Study Area

The Elgeyo Escarpment is located in Elgeyo Marakwet County, Kenya 00°10′00′′ N and 01°17′ 00′′N and Longitudes 35°30′00′′E and 35° 43′00′′E (Figure 1). It covers an area of approximately 815.71 km$^2$. The Escarpment runs 140 km long and approximately five kilometres wide on average extending from a height of 1400 to 2800 masl (Kilimo, 2014). It cuts across the four sub-Counties of Keiyo North, Keiyo South, Marakwet East and Marakwet West and is inhabited by approximately 126,000 people (KNBS, 2019). The temperatures can be as high as 30°C during the dry season and as low as 17° C during the rainy season. It receives 1000 to 1400 mm rainfall per annum, which is bi-modal with the long rains usually falling between March and July while the short rains fall between August and November (KMD, 2020).

The escarpment forms parts of Elgeyo Hills and Cherangany Hills water tower ecosystems (Rouillé-Kielo, 2021). These ecosystems are a source of many rivers that form the main water divide running along the Escarpment. East of the water divide is the Kerio catchment area that drains into Lake Turkana (Figure 1) while West of the divide is the Lake Victoria Basin which drains into Lake Victoria (Sombroek *et al.*, 1982). Chromic cambisols, humic nitisols and lithic leptosols constitute the major soil types in the escarpment, mainly developed on gneisses (Sombroek *et al.*, 1982). Other soil types include humic cambisols, eutric cambisols and haplic lixisol and eutric gleysols soils developed on basic igneous rocks in Iten and Kamwosor and surrounding areas (Jaetzold *et al.*, 1982). Agriculture is the main economic mainstay in the area where crops are grown and livestock kept. Maize, Irish potatoes, beans, sorghum, millet and fruits are grown in the various agro-ecological zones. Dairy and beef cattle, poultry, sheep and goats are kept in the area besides sporting activities (Muchemi *et al.*, 2002).

### Land use land cover change assessment

Two time period multispectral Landsat (Landsat 5 TM satellite image for 6$^{th}$ February, 1995 and Landsat 8 OLI satellite image for 11$^{th}$ February, 2020) were acquired from the United States Geological Survey Website. The area shapefile was obtained from contour interpolation and tracing contour values from 1200 m – 2800 m. Study area digital and topographic maps were acquired from Survey Department of Kenya. The images were pre-processed

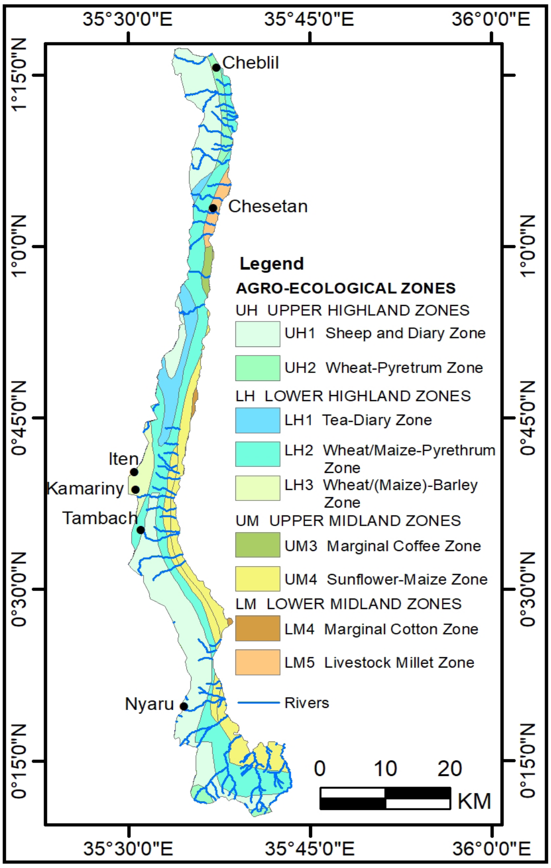


**Figure 1**: Agro-ecological zones and drainage system in Elgeyo Escarpment

and classified by grouping all the pixels in the satellite image into LULC information classes and accuracy assessment done. Change detection was performed on the images using ArcMap 10.4 to determine spatio-temporal LULC conversions and Ground truthing done by field observations and surveys. The LULC classes in the study in 1995 and 2020 are as illustrated in Figure 2.

**Soil erosion assessment**

Soil loss are computed through various models, one of them being the Revised Universal Soil Loss Equation (RUSLE), a tool employed to evaluate soil loss spatially and temporally (Renard *et al.*, 1991). The tool is an improvement of the universal soil loss equation (USLE) to enhance its accuracy in estimation of soil loss (Renard, 1997). The key components in the estimation of soil erosion are, precipitation, soil physical properties, topographic data from a digital elevation model (DEM), LULC and soil conservation practices (Wischmeier *et al.*, 1978). The annual soil erosion for the period in the escarpment was computed using the following formula:

$$A = R * K * (LS) * C * P \qquad (1)$$

where:

A = Annual average soil loss per unit area (t/ha/yr), R = Rainfall erosivity factor (MJ mm/ha/h/yr), K = Soil erodibility factor (ton hmj/mm), LS = slope length and slope steepness factor (dimensionless), C = Cover management factor (dimensionless), P = soil conservation support practice factor (dimensionless).

**Rainfall erosivity (R) factor determination**

Since there is strong positive association between precipitation intensity and soil erosion, the R-factor remains the major driver of soil erosivity (Kogo *et al.*, 2020). Rainfall data, which is a key input for determining the rainfall erosivity, was acquired from the Kenya Meteorological Department. In areas with no rainfall intensity data, the storm erosivity index values were used instead to estimate erosivity following the Wischmeier and Smith equation (Wischmeier *et al.*, 1978). The rainfall data over a time span of 1995–2020 was used to determine erosivity for the period. 1995 served as the base period with 2020 being the current period.

$$R = \sum_{i=1}^{12} 1.735 \, x \, 10 \wedge \left(1.5 \, log \, 10 \left(\frac{pi^2}{p}\right) - 0.08188\right)$$

(2)

where, R is the rainfall erosivity in MJ mm/ha/h/yr), Pi is rainfall in millimetres for the month and P is the yearly rainfall in millimetres. R-factor values for the sampled points were processed using Kriging technique to derive their geographical position in the escarpment (Lu *et al.*, 2004).

**Soil erodibility (K) factor**

The K factor indicates the soil particles power to resist detachment by raindrops and be transported by rainfall runoff (Renard, 1997). The K factor relies on the soil's intrinsic properties like organic matter, texture, structure

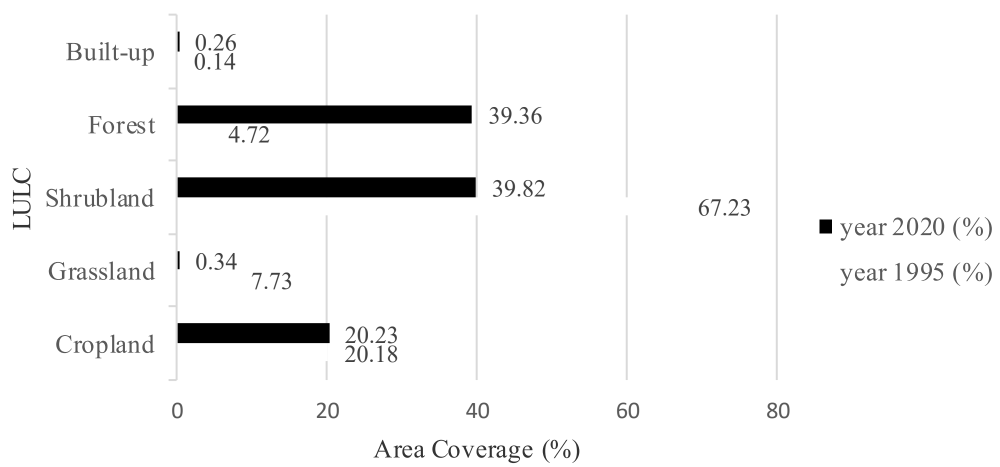


**Figure 2:** Spatio-temporal land use land cover in Elgeyo Escarpment (1995 and 2020)

and permeability (Sujatha *et al.*, 2018). The soil data was sourced from the Kenya Soil and Terrain Database (KENSOTER, 2004) and estimated following the erosion productivity impact calculator model (Sharpley *et al.*, 1990):

$$K_{Rusle} = f_{csand} \times f_{cl\text{-}si} \times f_{orgC} \times f_{hisand} \quad (3)$$

$$f_{csand} = 0.2+0.3 \text{ x } \exp[-0.256 \text{ x Ms x } (1-M_{silt}/100)] \quad (4)$$

$$f_{ci\text{-}si} = [M_{silt} / M_c + M_{silt}]0.3 \quad (5)$$

$$f_{orgc} = 0.0256 \text{ x Mo/ Mo} + \exp[3.72- (2.95 \text{ x Mo})] \quad (6)$$

$$f_{hisand} = \frac{1-0.7 \text{ x } 1- \text{Ms}/100}{(1-\text{Ms}/100) + \exp[-5.51 + 22.9 \text{ x } (1-\text{Ms}/100)]} \quad (7)$$

where Ms, $M_{silt,}$ Mc and Mo are the % sand, % silt, % clay and % organic matter, respectively.

The K-factor values range between 0 and 1, with values tending towards 1 denoting increased susceptibility to water erosion (Sharpley *et al.*, 1990).

**Land topographic (LS) factor**

The LS factor is the merged influence of the topographic length and steepness on soil loss (Morgan *et al.*, 1984). Increasing slope length and steepness values accelerates erosion rates because they yield higher overload flow speed (Morgan *et al.*, 1984). Shuttle Radar Topography Mission (SRTM) dataset with 30 m resolution accessed from USGS Earth Explorer website was utilized. Additionally, the LS factor was calculated from the ArcGIS hydrology tool and the facet slope angle calculated from the DEM. The LS factor is estimated using the Matlock model (Matlock *et al.*, 2011):

$$LS = (\lambda / 22.13) \text{ m x } (0.065 + 0.045 \text{ s } +0.0065 \text{ s}^2) \quad (8)$$

In this equation, $\lambda$ = slope length; a product of flow build-up and cell resolution (30 m for the study), s = percentage slope gradient; m = dimensionless exponent based on land steepness. The m values are allocated as: 0.5, 0.4, 0.3 and 0.2 for slopes of >5%, 3–5%, 1–3% and <1%, in that order (Srinivasan *et al.*, 2019).

**Conservation support practice (P) factor**

The P factor is the description of land management control actions that are geared to minimize rate of runoff water and by extension soil erosion. This study utilized LULC evaluation images for 1995 and 2020. The images were combined with slope attributes computed from the DEM using 'union function' in ArcGIS to derive P-factor values (Wischmeier *et al.*, 1978). By convention, the conservation practice factor value of 1 denotes poor conservation practices while 0 denotes proper utilization of conservation measures. There are three conservation measures most practised in the area namely; terracing, contouring and strip cropping (Muchemi *et al.*, 2002).

**Cover management (C) factor**

The C factor is an essential component of the RUSLE model since it is the value of the contribution of land cover to soil loss (Yang, 2014). The value of cover management factor was computed using the Normalized Difference Vegetation Index (NDVI), mostly estimated using Van der Knijff equation (Van der Knijff *et al.*, 2000):

$$C = \exp[-a \text{ x NDVI} / \beta - \text{NDVI}] \quad (9)$$

In this model a = 2, $\beta$ = 1. Conventionally, C factor values are between 0 and 1 with 0 denoting complete vegetation cover while 1 denotes bare lands (Gitas *et al.*, 2009).

**Spatial and temporal distribution of soil loss**

Spatio-temporal soil losses were computed by projecting the extracted layers for each of the RUSLE factors to WGS 1984 UTM Zone 37 N spatial reference and resampled to a 30 × 30 m pixel size. These layers were overlaid in ArcGIS to obtain soil loss risk maps for the study years. The produced maps were grouped into various soil loss categories. Once the erosion risk maps were generated, mean amounts of soil erosion were calculated under different altitude and slope zones. Further, the input of LULC and conversions to soil erosion susceptibility in the escarpment across slope zones were estimated using conversion computation technique.

## RESULTS

**RUSLE factors**

The rainfall erosivity (R-factor) values ranged from 394.07 to 910.30 MJ mm/ha/h/yr with a mean of 652.19 MJ mm/ha/h/yr in 1995 (Figure 3a). The 2020 rainfall erosivity ranged between 1071.03 and 2649 MJ/mm/ha/hr/yr with mean erosivity value of 1378.02 MJ mm/ha/h/yr (Figure 3b). The soil erosivity factor (K-factor) and LS factor are illustrated in Figures 3c and 3d.

The cover management (C-factor) had values ranging from 0 to 1 with 0 denoting complete vegetation cover while 1 denotes bare lands (Figure 4a and b). Likewise, the conservation practice (P-factor) values ranged from 0 to 1 with 0 and 1 denoting good conservation and poor conservation practices, respectively (Figure 4c and d).

TABLE I- SPATIO-TEMPORAL DISTRIBUTION OF SOIL LOSS IN THE ELGEYO ESCARPMENT

| Year | Soil erosion range (t/ha/yr) | Mean Soil erosion rate (t/ha/yr) | Total soil loss (t/yr) |
|---|---|---|---|
| 1995 | 0 – 49.42 | 14.02 | 407.46 |
| 2020 | 0 – 68.85 | 18.76 | 460.14 |

**Spatial and temporal soil losses**

Soil lost through sheet and rill erosion in the escarpment for 1995 and 2020 are shown in Table I. The mean erosion rates for 1995 and 2020 were 14.02 t/ha/yr and 18.76 t/ha/yr, respectively. These resulted in total soil losses of 407.46 t//yr and 460.14 t/yr in 1995 and 2020, respectively (Table I).

Soil loss was classified into four different soil erosion severity classes comprising, slight (less than 5 t/ha/yr), moderate (5-10 t/ha/yr), high (10-20 t/ha/yr) and very high (> 20 t/ha/yr), as indicated in Table II. The areas that encountered slight, moderate, high and very high erosion measured 26,878.86 ha, 966.51 ha, 1,797.84 ha, and 50,928.03 ha, respectively in both 1995 and 2020. The

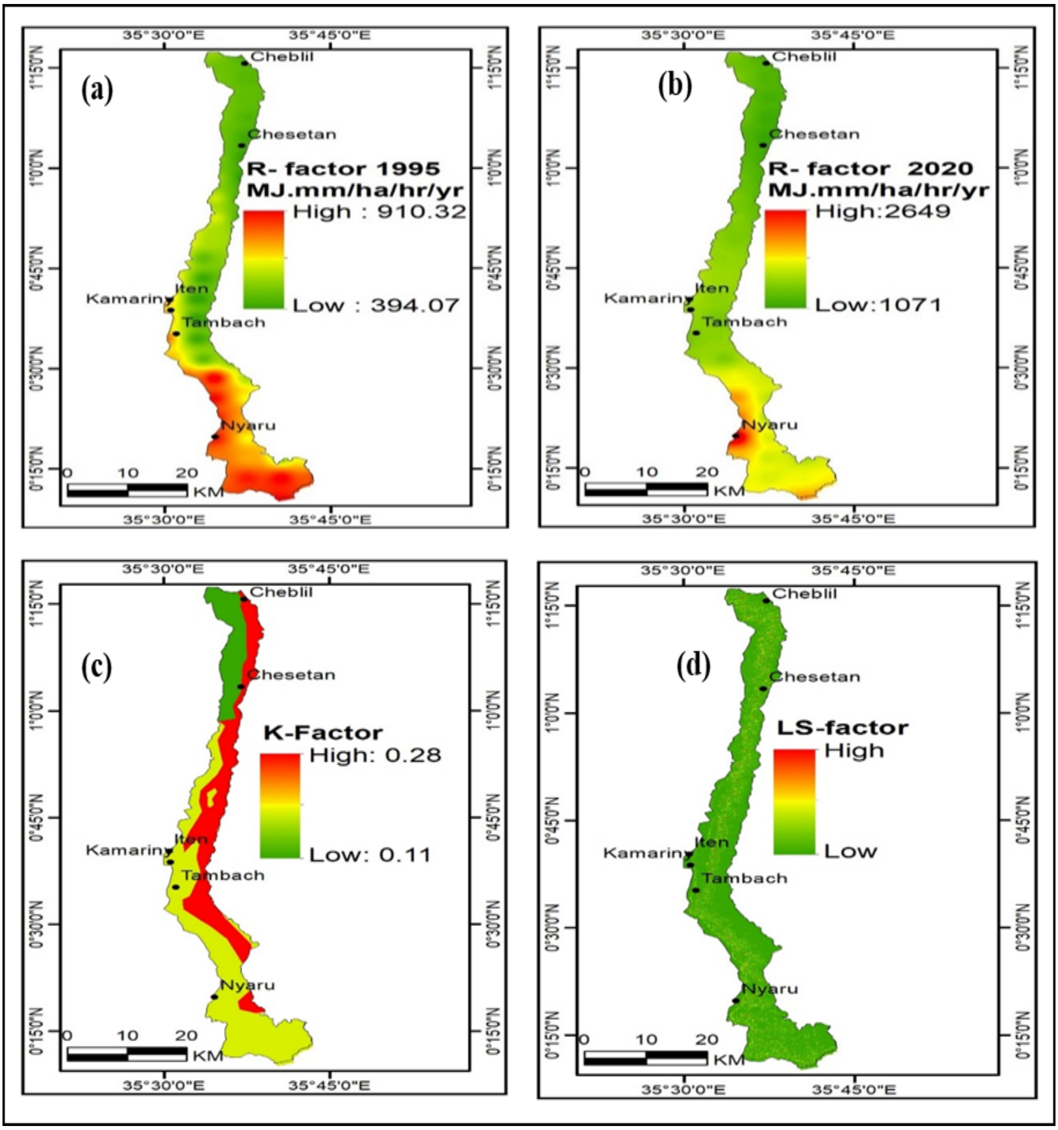


**Figure 3**: Spatial distribution of rainfall erosivity; (a) and (b), soil erodibility (c) and LS factor (d).

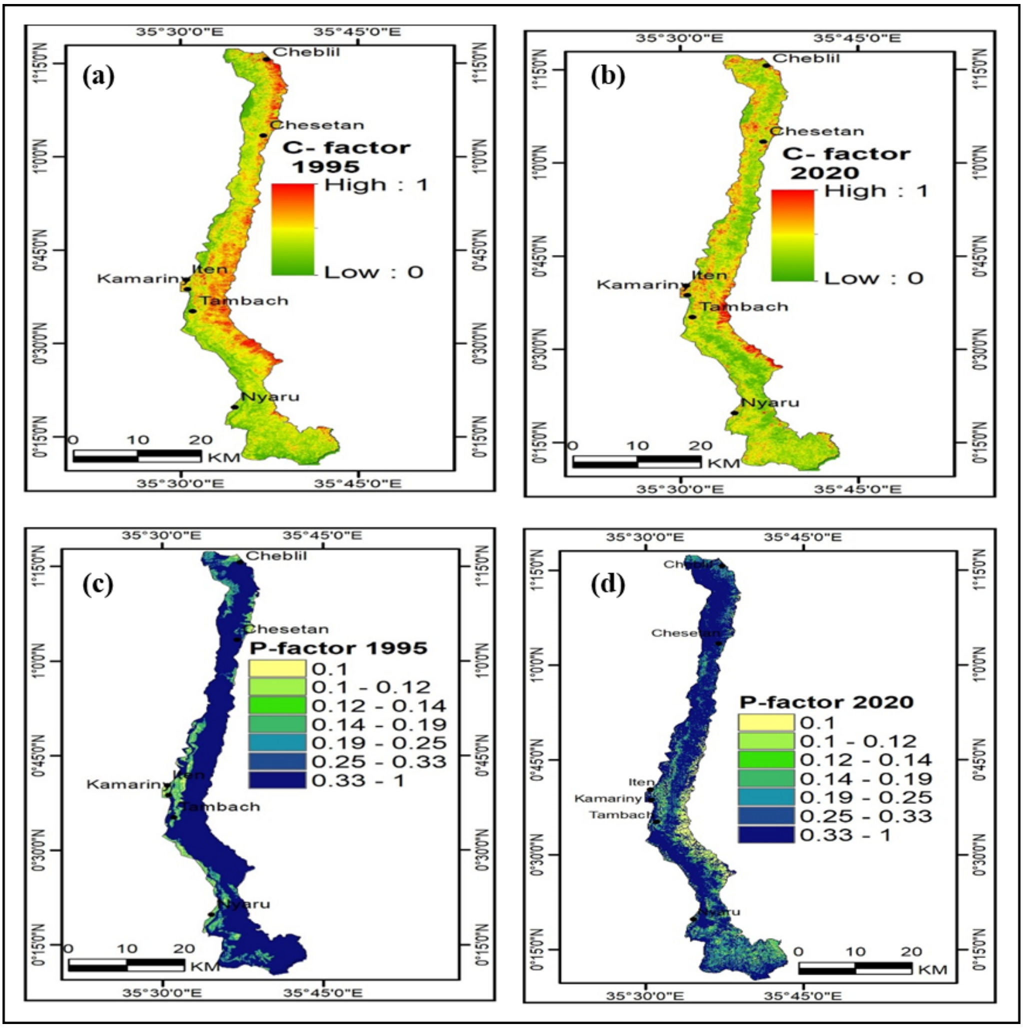


**Figure 4**: Distribution of cover management (C) a and b and conservation practice (P-factor) c & d

average soil erosion rates in the slight severity class were 0.39 t/ha/yr and 0.42 t/ha/yr in the years 1995 and 2020, respectively. The moderate soil erosion rates were 6.61 t/ha/yr and 6.68 t/ha/yr. The high erosion rates were 13.23 t/ha/yr and 13.16 t/ha/yr 1995 and 2020, respectively. Very high erosion was the most dominant severity class with soil erosion rates of 24.78 t/ha/y and 26.51 t/ha/y in years 1995 and 2020, respectively.

**Estimated rates of soil erosion by elevation**

The erosion rates in the area for elevation less than 1400 m (19209.6 ha) were 0.05 and 1.22 t/ha/yr in 1995 and 2020, respectively. The rates of soil loss for elevation 1400-1800 m (21191.1 ha) were 0.40 and 0.36 ton/ha/yr in 1995 and 2020, respectively. The rate of soil loss for elevation of 1800-2200 m (23355.9 ha) are 0.57 and 0.59 ton/ha/yr in 1995 and 2020, respectively. Soil erosion in

TABLE II -SPATIAL DISTRIBUTION OF SOIL LOSS UNDER DIFFERENT SEVERITY CLASSES IN THE ELGEYO ESCARPMENT

| Severity class | Soil loss (t/ha/yr) | 1995 | | 2020 | | Net change (t/ha/yr) |
|---|---|---|---|---|---|---|
| | | Area (ha) | Soil loss (t/ha/yr) | Area (ha) | Soil loss (t/ha/yr) | |
| Slight | <5 | 26,878.86 | 0.39 | 26,878.86 | 0.42 | 0.03 |
| Moderate | 5 to 10 | 966.51 | 6.61 | 966.51 | 6.68 | 0.07 |
| High | 10 to 20 | 1,797.84 | 13.23 | 1,797.84 | 13.16 | -0.07 |
| Very High | >20 | 50,928.03 | 24.78 | 50,928.03 | 26.51 | 1.73 |

the elevation 2200-2600 m (15,400 ha) were 0.25 and 0.52 ton/ha/yr in 1995 and 2020, respectively. The soil erosion in the areas with elevation exceeding 2600 m (2848.5 ha) are 0.1 and 0.28 ton/ha/yr in 1995 and 2020, respectively.

TABLE III - SOIL EROSION RATES IN DIFFERENT ELEVATION ZONES IN THE ELGEYO ESCARPMENT

| Elevation (masl) | Area (ha) | Soil erosion (t/ha/yr) | | Net change (t/ha/yr) |
|---|---|---|---|---|
| | | 1995 | 2020 | |
| <1400 | 19,209.6 | 0.05 | 1.22 | 1.17 |
| 1400-1800 | 21,191.1 | 0.40 | 0.36 | -0.04 |
| 1800-2200 | 22,355.9 | 0.57 | 0.59 | 0.02 |
| 2200-2600 | 15,400 | 0.25 | 0.52 | 0.27 |
| >2600 | 2,848.5 | 0.10 | 0.28 | 0.18 |

**Estimated rates of soil erosion by slope**

Soil erosion was further distributed according to slope of occurrence (Table IV). The results show an increase in erosion with increase in slope angle. The area (12195.1 ha) with slope angle of less than $5^o$ had the lowest erosion rates of 0.08 and 0.07 t/ha/yr in 1995 and 2020, respectively. In slopes of $5^o$-$10^o$ (13155.5 ha), soil losses were 0.18 and 0.20 t/ha/yr for 1995 and 2020, respectively. Similarly, soil loss in the slopes of $10\text{-}20^0$ (22433.9 ha) were 0.35 and 0.40 ton/ha/yr in 1995 and 2020, respectively. The same trend is maintained in the slope angle of $20\text{-}30^0$ (17577.9 ha) where soil losses were 0.60 and 0.69 ton/ha/yr in 1995 and 2020, respectively. The area (15731.7 ha) with a slope angle $>30^0$ exhibited a similar trend of increased soil loss recording 0.97 and 1.10 t/ha/yr for 1995 and 2020, respectively.

TABLE IV - SOIL EROSION IN SLOPE ZONES IN THE ELGEYO ESCARPMENT

| Slope (Degrees) | Area (ha) | Erosion (t/ha/yr) | | Net change (t/ha/yr) |
|---|---|---|---|---|
| | | 1995 | 2020 | |
| <5 | 12,195.1 | 0.08 | 0.07 | -0.01 |
| 5-10 | 13,155.5 | 0.18 | 0.20 | 0.02 |
| 10-20 | 22,344.9 | 0.35 | 0.40 | 0.05 |
| 20-30 | 17,577.9 | 0.60 | 0.69 | 0.09 |
| >30 | 15,731.7 | 0.97 | 1.10 | 0.13 |

**Contribution of land use/cover classes and conversions to soil erosion**

Occurrence of soil erosion under different land use /cover classes indicated that shrub land had the highest erosion occurrence of 67.1% and 39.8% in 1995 and 2020, respectively (Figure 5). Soil erosion in cropland remained largely constant at 20.1% and 20.2% in 1995 and 2020, respectively. In forest, soil erosion depicted an increasing pattern over the period. In 1995, the soil loss was 4.8% increasing to 39.4% by 2020. Grassland and built-up areas had a minimal soil loss throughout the period.

The major forms of land use land cover conversions among various LULC classes and the resultant corresponding total soil loss in tons (t) and average soil loss per hectare (t/ha) are presented in Table V.

The magnitude of LULC conversions in the various slope categories during the study period (1995-2020) is presented in Table VI. The results indicate that shrub/grassland lost substantial area to forest and cropland across all slope angles. Notably, shrub/grassland recorded the highest conversion to the tune of 6491.52 ha and 5671.98 ha to forest in areas with slope angles of $10\text{-}20^0$ and $20\text{-}30^0$, respectively. The conversion of cropland to shrub/grassland maintained a steady increase from slopes of $<5^0$ to $30^0$ (921.42 ha), $5\text{-}10^0$ (1538.28 ha) and $10\text{-}20^0$ (2040.21 ha). It however, declined at slope of $20\text{-}30^0$ and $>30^0$ to 1047.15 ha and 503.55 ha, respectively. The conversion of forest to cropland and shrub/grassland was highest; 128.34 ha and 241.74 ha respectively at slopes $10\text{-}20^0$ and that greater than $30^0$ (Table VI).

TABLE V- SOIL EROSION UNDER VARIOUS LULC CONVERSION CLASSES IN ELGEYO ESCARPMENT

| LULC conversions | 1995-2020 | | |
|---|---|---|---|
| | Area (ha) | Erosion (t) | Average soil erosion (t/ha) |
| Cropland - Shrub/grassland | 6,076.98 | 856.85 | 0.14 |
| Cropland - forest | 4,991.85 | 969.81 | 0.19 |
| Cropland - built-up | 119.79 | 41.93 | 0.35 |
| Shrub/grassland - forest | 24,250.77 | 11,396.50 | 0.47 |
| Shrub/grassland - cropland | 10,664.55 | 7,638.08 | 0.72 |
| Shrub/grassland - built-up | 81.81 | 74.18 | 0.91 |
| Forest - cropland | 453.51 | 233.38 | 0.51 |
| Forest - shrub/grassland | 690.12 | 184.74 | 0.27 |
| Forest - built-up | 0.27 | 0.08 | 0.31 |
| Built-up - cropland | 4.77 | 7.25 | 1.52 |
| Built-up - forest | 34.64 | 15.94 | 0.46 |
| Built-up - shrub/grassland | 35.01 | 11.20 | 0.32 |

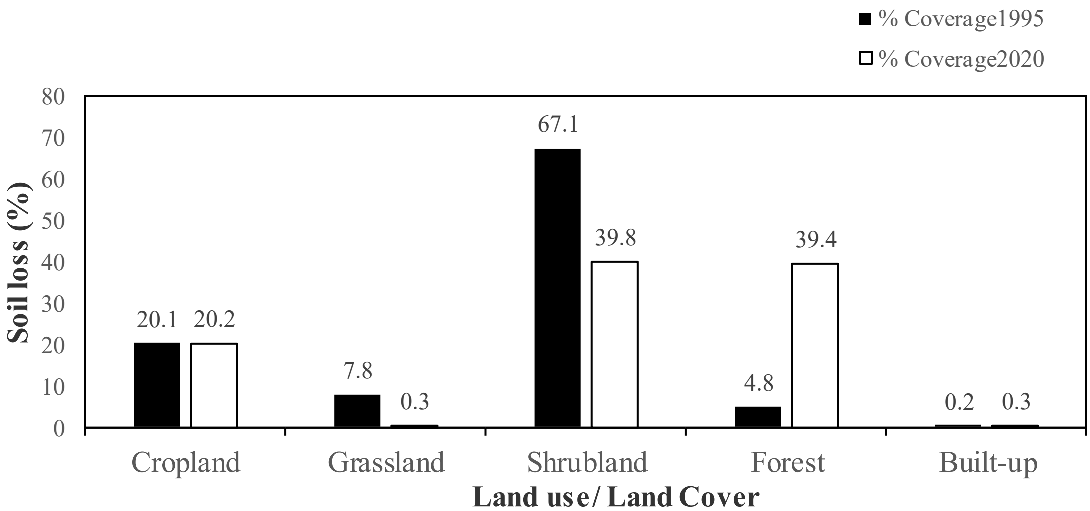


**Figure 5**: Contribution of various land uses to total soil erosion in Elgeyo Escarpment

TABLE VI- LAND USE LAND COVER CHANGES UNDER DIFFERENT SLOPES (1995-2020) IN ELGEYO ESCARPMENT

| LULC | Area Conversions under Different Slopes | | | | | Total ha |
|---|---|---|---|---|---|---|
| | <5 | 5-10 | 10-20 | 20-30 | >30 | |
| Cropland - shrub/grassland | 921.4 | 1538.3 | 2040.2 | 1047.2 | 503.6 | 6050.6 |
| Cropland - forest | 1040.3 | 1473.4 | 1461.3 | 618.7 | 350.9 | 4944.6 |
| Cropland – built-up | 49.8 | 45.2 | 19.7 | 3.8 | 3.3 | 121.8 |
| Shrub/grassland - forest | 3071.3 | 3506.5 | 6491.5 | 5672.0 | 5483.7 | 24224.9 |
| Shrub/grassland - cropland | 1046 | 954 | 2899.2 | 2801.0 | 2938.9 | 10639.6 |
| Shrub/grassland - built-up | 28.4 | 14.9 | 15.9 | 14.0 | 8.6 | 81.8 |
| Forest - cropland | 64.4 | 81.5 | 128.3 | 85.6 | 84.7 | 444.5 |
| Forest - shrub/grassland | 47.9 | 91.5 | 161.7 | 143.2 | 241.7 | 686.1 |
| Forest – built-up | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.3 |
| Built-up - cropland | 0.7 | 0.5 | 1.3 | 1.4 | 1.3 | 5.1 |
| Built-up - forest | 17.5 | 9.1 | 5.7 | 1.5 | 1.0 | 34.7 |
| Built-up - shrub/grassland | 14.5 | 9.0 | 6.2 | 4.7 | 2.0 | 36.4 |

During this period, soil erosion was observed to take an almost similar trend to LULC conversions at various slopes although it increased with an increase in slope angle (Table VII). The average soil erosion (t/ha) was computed using total hactares under different slopes and total soil erosion under different LULC change in different slopes to segregate and move into suspension (Umesh *et al.*, 2011). This finding is thus consistent with the observation of Yang (2014), that soil loss is proportional to the rate of rainfall erosivity barring changes in all other factors.

Higher erosion occurred in the mid to lower altitudes of the escarpment. This can be attributed to soil characteristics, slope angle and length and LULC dynamics. The stability of soil structure depends on its physical and chemical properties with the proportion of organic matter content contributed by decaying leaves and grass falling off from the vegetation being a key component. However, the vegetation cover is very low in these sections of the and therefore low organic matter implying that soil stability is lowered resulting in higher soil erosion (Thomas *et al.*, 2018; Umesh *et al.*, 2011). Further, the sections of the escarpment with high soil erodibility depict a higher slope angle and length. This occasions low infiltration and high runoff velocity during precipitation events (Kathwas *et al.*, 2021).

TABLE VII- SOIL EROSION UNDER DIFFERENT LULC CHANGES IN DIFFERENT SLOPES (1995 - 2020)

| LULC Conversion | Soil Erosion under different slopes | | | | | Total (tons) | t/ ha |
|---|---|---|---|---|---|---|---|
| | <5 | 5-10 | 10-20 | 20-30 | >30 | | |
| Cropland-shrub/grassland | 128.5 | 716.6 | 2756.3 | 3206.6 | 2643.8 | 9451.8 | 1.6 |
| Cropland - forest | 988.6 | 3928.9 | 8844.2 | 7326.9 | 5941.0 | 27029.6 | 5.5 |
| Cropland - built-up | 46.1 | 105.6 | 128.8 | 77.0 | 108.0 | 465.4 | 3.8 |
| Shrub/grassland-forest | 5095.9 | 15470.9 | 52738.9 | 68078.5 | 91403.3 | 232787.4 | 9.6 |
| Shrub/grassland-cropland | 1304.7 | 2704.1 | 15116.2 | 23760.6 | 41589.4 | 84475.0 | 7.9 |
| Shrub/grassland–built-up | 51.3 | 45.4 | 223.3 | 308.9 | 192.6 | 821.5 | 10.0 |
| Forest - cropland | 36.1 | 147.3 | 400.6 | 537.5 | 1337.4 | 2458.9 | 5.5 |
| Forest - shrub/grassland | 3.9 | 24.6 | 190.2 | 439.6 | 1339.0 | 1997.2 | 2.9 |
| Forest – built-up | 0.0 | 0.0 | 0.1 | 0.8 | 0.0 | 0.9 | 3.5 |
| Built-up - cropland | 0.7 | 1.6 | 11.8 | 21.9 | 44.8 | 80.8 | 15.8 |
| Built-up - forest | 49.5 | 45.9 | 34.3 | 20.3 | 26.7 | 176.6 | 5.1 |
| Built-up- shrub/grassland | 3.8 | 4.6 | 8.1 | 13.6 | 18.3 | 47.8 | 1.3 |

## DISCUSSION

Soil erosion in the Elgeyo escarpment was assessed using the RUSLE model in geographic information system (GIS) realm. The findings show that spatial distribution of rainfall erosivity in the escarpment is directly proportional to the amount of rainfall received in the area. The rainfall erosivity rates differed spatially. For example, the highest erosivity rates computed are higher in the southern sections of the study area particularly in Keiyo South part of the escarpment compared to the central and northern parts of the escarpment. In general, high erosivity rates in the area were more likely to occur during long rainy season from March - May (Mugalavai *et al.*, 2008).

Soil erosion occurs upon the action of rain on the soil thus the amount of erosion will depend on the combination of the potency of the rain and the capacity of the soil to resist erosion (Nanko *et al.*, 2008). As raindrops fall, they acquire kinetic energy and on impact, the kinetic energy is expended in the detachment of soil particles (Liu *et al.*, 2018). Once the raindrops hit the surface, they either infiltrate, evaporate or form runoff that flow down the slope gaining kinetic energy which is responsible for scouring action on land surface (Lim *et al.*, 2015; Salles *et al.*, 2000). Moreover, as the rain continues, the soil continue wetting to saturated conditions, making the soil attractive forces less than repulsive forces thus helping soil particles

The lowest soil loss rate in the escarpment of 0.39 t/ha/yr (slightly severe) was found in areas with gentle slope, well conserved vegetated areas hence low erosion severity. This was because these conditions are less prone to soil erosion (Morgan *et al.*, 1984; Muchemi *et al.*, 2002). On the other hand, very high erosion rates of 26.51 t/ha/yr were found in very steep, low vegetated and poorly conserved areas of the escarpment, since these conditions are proneto soil erosion owing to raindrops and runoff kinetic energy actions (Li *et al.*, 2019). These results are comparable and consistent with those of other past studies including soil erosion in western Kenya by (Kogo *et al.*, 2020) and protected areas of coastal Kenya by (Hategekimana *et al.*, 2020). The similarities are due to resemblances mainly in topographic characteristics, erosivity, erodibility and vegetation cover (Lim *et al.*, 2015).

The estimated mean erosion for the years 1995 and 2020 at 14.02 t/ha/yr and 18.76 t/ha/yr, respectively are higher than the tolerable mean soil erosion range of 5 t/ha/yr to 11 t/ha/yr (Angima *et al.*, 2003; Weldu Woldemariam *et al.*, 2020). The mean soil losses are also higher than the estimated mean soil losses of 6.26 t/ha/yr and 7.14 t/ha/yr in 1990 and 2015, respectively in the Kenya great Rift Valley Region as reported by (Watene *et al.*, 2021). This can be attributed to differences in slope characteristics of the areas. Although Elgeyo Escarpment, forms part of the great Rift Valley, its slope is steeper compared to that of the Kenya great Rift Valley whose terrain comprises of highlands, escarpments and plateaus. However, they fall within the tolerable limits less than 25 t/ha/yr for mountainous landscapes (Koirala *et al.*, 2019) and the African erosion range of 10.8-146 t/ha/yr (Stocking, 1984) owing to the similarities in topographic characteristics.

The results indicate that over 63% of the escarpment falls within the very high erosion severity class since it experiences very high erosion greater than 20 t/ha/yr. About 33.4% of the escarpment experience soil erosion of low severity because it is located in low slope angle and fairly vegetated parts of the escarpment. The contribution of the two soil erosion severity classes combined is extremely a huge area because of the expansive extent of their occurrence. Accordingly, there is need to review land use and land cover in the escarpment to ensure that this landscape is sustainably managed.

Results from spatial distribution of soil erosion risk indicate that the mid and lower altitudes within the escarpment experience higher soil loss rates cause, at this elevation, the slopes are often very steep making the velocity of rainfall runoff very high (Dulo *et al.*, 2010). These findings are consistent with those of Ziadat *et al.* (2013) and Mati *et al.* (2000) who found that the increase in slope steepness and slope length, increases the rate of soil erosion owing to the high velocity and runoff. High runoff velocity causes increase in shear stress on the soil surface, resulting in increase in silt delivery (Ali *et al.*, 2016). These results show that topographic characteristics, mainly slope length and steepness, greatly influence rates of soil loss. This is consistent with the results of Koirala *et al.* (2019) who observed that soil loss increased proportionally with steep slopes. The longer the slope length and higher slope angle, the higher the soil loss. The Elgeyo Escarpment is characterized by high slope length and steepness with almost 50% of its area being within a slope angle above $20^0$. In addition, there is low vegetation cover with low soil conservation structures and practices and high rainfall (1200 mm/year) in the escarpment. These factors, exacerbate soil erosion and leads to large flow accumulation downstream (Dulo *et al.*, 2010). The low vegetation cover in the highly erodible sections of the escarpment can be attributed to human activities including encroachment for settlement, deforestation and agriculture (Kogo *et al.*, 2021; Watene *et al.*, 2021).

The results established that soil erosion was highest in croplands compared to areas under forest, shrub/grasslands and built-up. This can be attributed to the increased population pushing people from the traditional farming areas to the escarpment. The expansion of agricultural activities results in a corresponding decline in shrub-land and grassland. As farming is continuously intensified to produce food for the growing population, the soil physical properties deteriorate. This makes the soil susceptible to erosion, leading to loss of organic matter, a key component for soil aggregate stability (Deng *et al.*, 2016). Although forests, shrub-land and grasslands are equally susceptible to soil erosion, the rates of soil erosion in these areas are often lower compared to croplands. This is due to vegetation cover that significantly lowers raindrops kinetic energy (Lim *et al.*, 2015).

In terms of nature and magnitude of changes among land use land cover classes, the results indicate that, shrub/grassland decreased significantly while forest gained dramatically. Built-up and croplands gained marginally. The gain in forest, built-up and croplands happened at the expense of shrub/grasslands. This kind of LULC change contributed to the widespread and highest quantities of soil erosion. The high rate of soil erosion (1.78 t/ha/yr) was recorded in built-up areas converted from shrub/grassland. The conversion of shrub/grassland to cropland resulted in marked increase in soil erosion. This can be attributed to increased exposure of soil making it prone to erosion. Further, the conversion of cropland to forest still resulted in soil erosion. This is consistent with the results of Schürz *et al.* (2020) and Kogo *et al*, (2020) who reported high erosion rates in forested areas located on highlands of West Pokot, Elgeyo Marakwet and Western Kenya, respectively. This could be attributed to the trees planted in the forest land having not established enough to prevent soil erosion occurrence. Moreover, soil conservation measures such as land terracing, an effective soil erosion control structure (Ruto *et al.*, 2017) that was hitherto available in cropland may have been abandoned when the land converted to forest (Taye *et al.*, 2015).

## CONCLUSION AND RECOMMENDATIONS

It was found in this study that RUSLE model is a rapid applicable method in identification of probable erosion areas and subsequent quantification of soil loss. The findings suggest that mean soil erosion rates are intolerable in the escarpment. Over 63% of the escarpment falls within the very high erosion severity class with erosion rate being >20 t/ha/yr. Topographic characteristics, particularly slope angle and length greatly influence rates of soil loss with areas having higher slope steepness ($>10^0$) experiencing highest rates of soil erosion. Land use land cover and change influences soil erosion occurrences and intensities. Higher soil erosion rates were prevalent in areas of the escarpment that had been converted from shrub/grasslands to built-up, croplands and forests.

To minimize soil erosion occurrence in the escarpment, the study recommends full land adjudication to facilitate proper enforcement of basic land use regulations that emphasize on soil conservation practices particularly prohibition of cultivation on steep slopes, land terracing and grass strips.

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