International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 4 Issue 11, November 2017

ISSN: 2394-4404

GIS-Based Determination Of RUSLE'S 'LS' Factor For River Nzoia Basin In Kenya

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***Abstract:** River Nzoia basin is a fragile ecosystem, environmentally. The basin experiences a range of problems; deforestation, soil erosion, sedimentation and flooding. Topography is one of the fundamental factors affecting soil erosion by water. The objective of this paper was to determine RUSLE'S 'LS' factor for river Nzoia basin in Kenya by use of GIS techniques. The main input data was a 90m Digital Elevation Model (DEM). The model was manipulated in a GIS environment to generate both 'L' and 'S' factors. The S-Factor value ranging from 3.84 to 45.9^0 indicated areas prone to more soil loss than areas with elevation less than 3.84^0. The L-factor had values ranging from a minimum of 0 to a maximum of 0.265 with 0.02 as mean and standard deviation. Values between 0.067 and 0.265 were mainly characterized with high elevation. Therefore, such areas would be more affected by soil erosion if L-factor is considered in isolation with the other RUSLE factors invariant. Raster calculator (ArcGIS spatial tool) was applied to compute the 'LS' factor. The LS factor varied from 0 to 0.30 with mean and standard deviation value of 0.02. Higher values of the LS-Factor were a characteristic of the high altitude areas of Mt. Elgon, Cheranganyi Hills and Nandi escarpment. The lowest LS-Factor values were attributes of low altitude areas where the topography is flat-like in nature. These areas cover parts of the middle and mainly the lower basins spanning up to the floodplains of the Nzoia River towards Lake Victoria. This study demonstrated utilization of spatial technologies (GIS tools) to generate RUSLE's 'LS' factor for river Nzoia basin. There is need to validate LS-factor using field measurements to provide a better estimate of the topographic effect on erosion and initiate suitable protection measures to lessen soil loss in river Nzoia basin.*

***Keywords:** River Nzoia basin; DEM; GIS; RUSLE; Soil erosion; LS-factor*

I. INTRODUCTION

According to Lal (2001), topography is one of the fundamental factors affecting soil erosion by water. Ordinarily, digital elevation models (DEMs) have been used to represent topography and for extraction of topographical and hydrological features for erosion hazard modeling in geographic information system (GIS) environment (Pawanjeet and Helmer, 2010; Zhang, *et al*., 2008). Slope is a principal topographical attribute and is determined from the spinoffs of the geographical surface (Pawanjeet and Helmer, 2010). Slope-length (LS) factor refers to the ratio of soil loss on a given slope length and steepness to soil loss from a slope which is 22 m long and 5 degree steep (Renard, *et al*., 1997). The RUSLE's LS-factor can incorporate complex slopes in order to provide a more accurate estimation of the topographic effect on soil erosion (Renard and Ferreira, 1993).

A. SLOPE LENGTH AND STEEPNESS (LS-FACTOR)

a. SLOPE LENGTH (L) FACTOR

Soo (2011) contends that, the slope and slope-length factors (*S* and *L*, respectively) account for the effect of topography on soil erosion. The factor represents a ratio of soil loss under given conditions. The steeper and longer the slope, the higher the risk of erosion. According to Renard and Ferreira (1997), the factor can be estimated through field measurement or from a digital elevation model (DEM). Wishmeier and Smith (1978) define L-factor as the distance from the source of runoff to the point where the slope decreases enough that deposition begins.

b. SLOPE (S) FACTOR

The hill slope-gradient factor, S, reflects the effect of hill slope-profile gradient on soil loss. It is defined as the change in elevation per change in horizontal distance, expressed as a percentage or in degrees (Zhang, *et al*., 2008). Soil losses increase more rapidly as gradient increases. The interaction of angle and length of slope has an effect on the magnitude of erosion and thus the two are always considered together (Morgan and Davidson, 1991). With the incorporation of DEM into GIS, the slope gradient (S) and slope length (L) can be determined accurately and combined to form a single factor known as the topographic factor LS. The slope length (L) and the slope(S) are respectively defined by Equations 1 and 2.

$$L = 1.4\left(A_s / 22.13\right)^{0.4} \quad ....1$$

and

$$S = \left(\frac{\sin\alpha}{0.0896}\right)^{1.3} \quad ....2$$

Where,

A_s - Specific contributing area (m^2)

α - Slope angle (degrees), estimated using a digital elevation model (DEM)

Equations 1 and 2 can be combined (Morgan and Davidson, 1991) by use of Equation 3, defined as;

$$LS = \sqrt{\frac{l}{22}}\left(0.065 + 0.045 * s + 0.0065 * s^2\right) \quad ....3$$

Where,

l -Slope length (m)

s - Percent slope

II. METHODS AND MATERIALS

A. STUDY AREA

The study was carried out in river Nzoia basin. The basin lies between latitudes $1^0 30'$ N and $0^0 05'$ S and longitudes 34^0 and$35^0 45'$ E. The river originates from the highlands of Mt. Elgon, Cheranganyi Hills, Nandi escarpment, and Kakamega forest. River Nzoia drains into Lake Victoria at an altitude of 1100 m above sea level (Nyadawa, *et al.*, 2010). The River measures about 334 km long with a basin area of about 12, 709 Km^2. The mean annual discharge is 1.740 X 10^9 m^3 (Githui, *et al.*, 2010). Mean annual rainfall varies from a maximum of 1100 to 2700 mm and a minimum of 600 to 1100 mm.

B. SLOPE-LENGTH (L) ESTIMATION

The process of generating the slope length was achieved stepwise, as outlined below;

- ✓ Depressions in the DEM of the basin were filled to ensure continuous flow of water
- ✓ The filled DEM was used as input to determine the flow direction of the basin area. This helped to identify the down-slope direction for each cell and showed surface water flow direction from any of the eight neighbouring cells.
- ✓ Flow direction was used as an input grid to derive the flow accumulation.
- ✓ Wischmeier and Smith (1978) note that, flow accumulation tool identifies how much surface flow accumulates in each cell and areas of zero flow accumulation e.g. mountain peaks.
- ✓ The flow accumulation was used as an input grid in the Drainage Network Extraction and Network Ordering of the basin area.
- ✓ The Drainage Network Ordering Map was used as an input to estimate the Flow Length (L- factor) of river Nzoia basin as expressed in Equation 1.

Both the length (L) and slope(S) factors were exported and stored in a tiff format layer to ensure compatibility in the spatial analyst tool (Raster calculator). Finally, the Raster calculator was used to input Equations 1 and 2 to compute LS factor, see Equation 3.

C. SLOPE (S) FACTOR

The slope component is a major input in the computation of the LS factor. Digital Elevation Model (DEM) was used to generate the slope using surface analysis under the spatial analyst tool. The calculation of the Slope factor was achieved by the use of Arc Hydro tool of ArcGis10.1 where the Raster DEM was used as an input. The slope function in Arc Hydro was applied and generated spatial distribution of the slopes in the basin. Figure 1 illustrates the methodology used to determine the LS-factor.

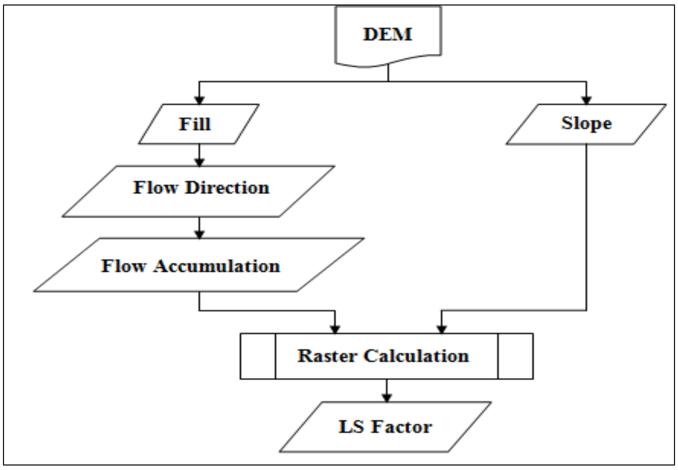

Figure 1: Methodology used to determine the LS-factor

III. RESULTS AND DISCUSSIONS

A. SLOPE AND SLOPE LENGTH (LS) FACTOR

Slope and slope length (LS) is a composite factor whose values are used to show the effects of topography. Low LS values depict areas with reduced slope and overland flow length and the contrary is true.

a. SLOPE (S) FACTOR

The slope of the basin had a value ranging from a minimum of 0 to a maximum of 45.93 degrees. Figure 2 shows the elevation raster dataset displayed using the classified renderer for S-factor spatial distribution.

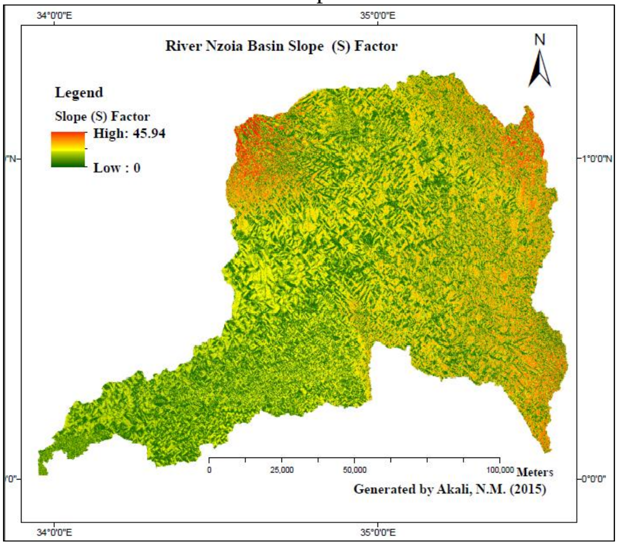

Figure 2: River Nzoia basin slope (S) factor

The S-factor respective mean and standard deviation parameters are 3.84 and 3.82 degrees, see Figure 3.

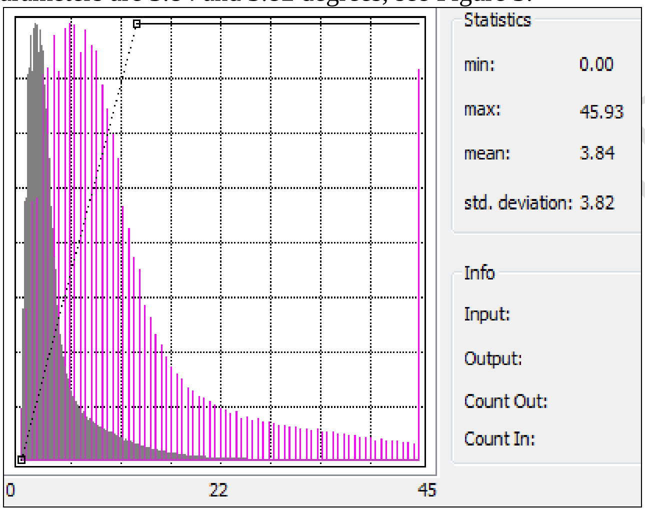

Figure 2: Histogram showing S-factor statistics

If other RUSLE factors are held constant, the S-factor alone will signify that the areas with elevation values ranging from 3.84 to 45.9^{0} will experience more soil loss than areas with elevation less than 3.84^{0} through erosion.

b. SLOPE LENGTH (L) FACTOR

The L-factor has values ranging from a minimum of 0 to a maximum of 0.26. The mean and standard deviation have a value 0.02, see Figure 3.

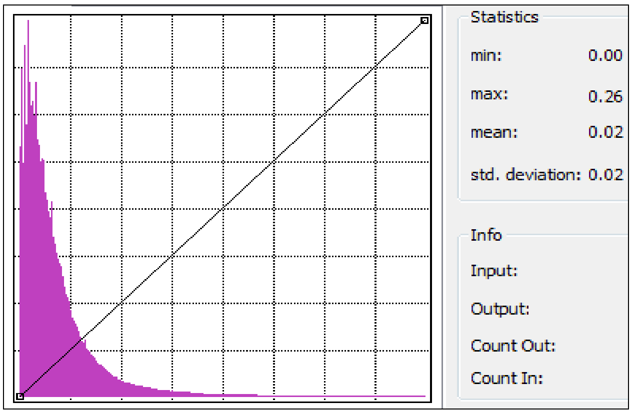

Figure 3: Histogram showing L-factor statistics

The L-factor map is shown in Figure 4.

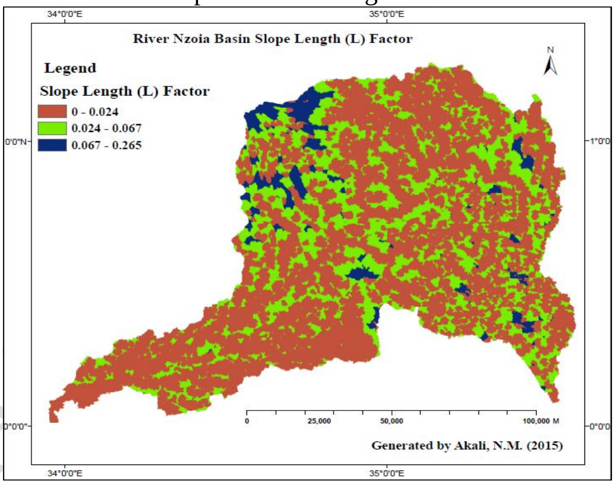

Figure 4: River Nzoia basin slope length (L) factor

The lowest values ranging from 0 to 0.024 are along the basin rivers since the pixels at this points have a shorter distance for water to flow and drain to the nearest outlets. If the influence of L-factor to soil erosion is considered, the areas close to the rivers will be less affected while areas far away will contribute more to the erosion experienced in the basin. These are the areas whose L-factor value ranges between 0.067 and 0.265 and are mainly characterized with high elevation. Therefore, such areas will be more affected by soil erosion if L-factor is considered in isolation. The slope (S) and slope length (L) factors were combined using Equation 3 to yield the topographic factor LS, see Figure 5.

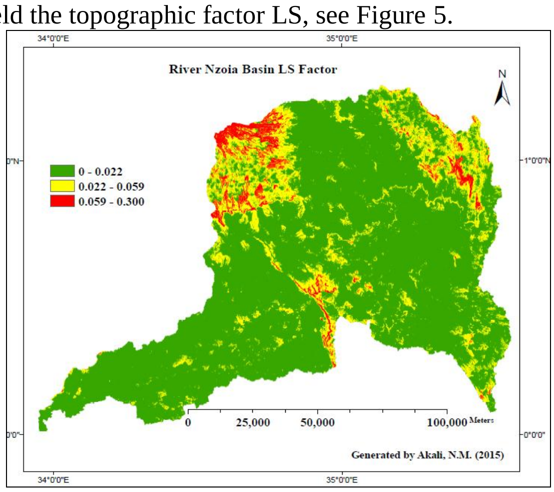

Figure 5: River Nzoia basin slope and slope length (LS) factor

The LS factor varied from 0 to 0.30 with mean and standard deviation of 0.02, see Figure 6.

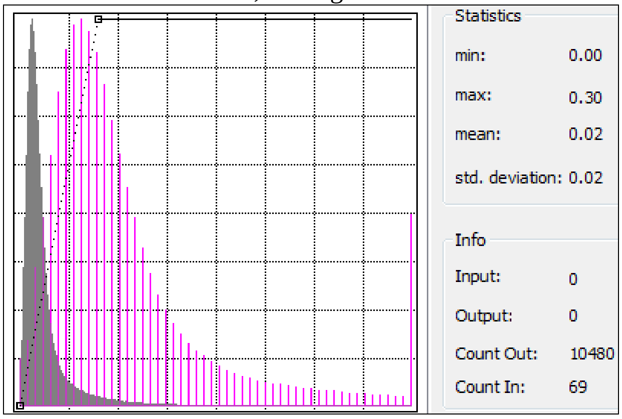

Figure 6: River Nzoia basin LS-Factor statistics

Areas near rivers have their LS-factor values tending to zero. This is a characteristic of both reduced slope and overland flow length. Regions with LS-factor values in the range of 0.02 to 0.30 are likely to experience high soil erosion levels if LS-factor is considered in isolation with the other RUSLE factors invariant.

IV. CONCLUSION

River Nzoia basin is an environmentally fragile ecosystem. The basin experiences a range of challenges; deforestation, soil erosion, sedimentation and flooding. This study demonstrated utilization of spatial technologies (GIS tools) to generate RUSLE's 'LS' factor for river Nzoia basin. Soil erosion is a phenomenon that is highly dependent upon the slope (S) and slope length (L), given other factors invariant. Higher values of the LS-Factor were a characteristic of the high altitude areas of Mt. Elgon, Cheranganyi Hills and Nandi escarpment. The lowest LS-Factor values were attributes of low altitude areas where the topography is flat-like in nature. These areas cover parts of the middle and mainly the lower basins spanning up to the floodplains of the Nzoia River.

V. RECOMMENDATION

There is need to validate LS-factor using field measurements to provide a better estimate of the topographic effect on erosion. Ground truthing to be undertaken on areas showing high vulnerability to soil erosion and initiate appropriate conservation measures to mitigate soil loss and restore environmental integrity of river Nzoia basin.

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