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Research Article

COMPARISON OF SLOPE LENGTH FACTOR ESTIMATION ALGORITHMS IN A GENTLY SLOPING TERRAIN

ANJITHA KRISHNA P.R.[1*], LALITHA R.[2], SHANMUGASUNDARAM K.[3] AND NAGARAJAN M.[4]

[1,2,3]Department of Soil and Water Conservation Engineering and Agricultural Structures, AEC&RI, TNAU, Kumulur, Trichy, 621712, India
[4]Department of Soil and Water Management Research Institute, Kattuthottam, Thanjavur, 613501, India
*Corresponding Author: Email-anjithakrishna100@gmail.com

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Abstract- The major uncertainty in soil erosion assessment studies is derived from LS factor constituting both slope length and slope steepness factor. Empirical soil erosion models employing different algorithms for estimation of LS factor using raster based DEMs. The present study compares two algorithms-Specific Contributing area (SCA) method and Cumulative Slope Length method (CSL), for estimation of slope length factor in a gently sloping terrain. The results showed that SCA method is the best performing method in gently sloping terrain since the effect of contour length exponent get minimized due to less influence from diagonal flow direction. The pixel to pixel based slope length exponent may result in more appropriate estimation of slope length factor in gently sloping terrains. The results from the study may be helpful in appropriate prediction of soil erosion in gently sloping terrains.

Keywords- Soil erosion, Slope length factor, SRTM, ASTER, SCA, CSL.

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Introduction

The slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough to begin the process of deposition or where the runoff water enters a well-defined channel. LS-factor in USLE/RUSLE models is the product of slope steepness factor(S-factor) and slope length factor (L-factor). As per USLE model recommendation, slope length factor, L can be represented as follows [6]:

$$L = \left(\frac{\lambda}{\lambda_u}\right)^m \qquad \text{... [1]}$$

where, λ= horizontal slope length, and λ_u = length of USLE unit plot, 22.1 m. The recommended values of m ranges from 0.2 to 0.5 as slope steepness increases from 0 to 5%; 0.5 was recommended for all slopes above 5%. The exponent was later modified considering rill and interrill erosion processes and deposition process by flow [3]. The newly developed relationship is as below:

$$\beta = \frac{\left(\frac{\lambda}{22.13}\right)\left(\frac{sin\theta}{0.0896}\right)}{(3.0\, sin^{0.8}\theta + 0.56)} \qquad \text{... [2]}$$

[2] described a method for calculating cumulative downhill slope length (CSL) for USLE model using regular grid DEMs. The CSL method calculates slope length from the DEM data in the flow direction from the highest points in the area covered by DEM. The methodology accounts for the concavity and convexity in the terrain [1] automated a two-dimensional formulation of the concept for calculating LS-factor for topographically complex terrain and were compared with the manual method. The L-factor for such a slope segment can be calculated as:

$$L_{i,j} = \frac{\left(A_{i,j-in} + D^2\right)^{m+1} - A_{i,j-in}^{m+1}}{(D\,)^{m+2} x_{i,j}^{m} (22.13)^m} \qquad \text{... [3]}$$

where $A_{i,\,j\text{-}n}$=contributing area at the inlet of a grid cell with coordinates (i, j) (m^2); $D_{i,\,j}$=the effective contour length (m) which is calculated as below:

$$D_{i,j} = D\left(sin\alpha_{i,j} + cos\alpha_{i,j}\right) = D\, x_{i,j} \qquad \text{... [4]}$$

where D=the grid size (m), $\alpha_{i,\,j}$=aspect direction for the grid cell with coordinates (i, j). The present study compares the cumulative slope length (CSL) and Specific Contributing Area (SCA) approaches for L-factor estimation using two open source DEMs-SRTM and ASTER, since the LS-factor is considered as the uncertainty component in the erosion models [5].

Materials and Methods

Study Area

The study area located within Thiruchirapalli district in Tamil Nadu state, India with an of 3656.83 hectares and 34.07897 km perimeter. The study area falls between 10° 59' 11.9" North to 11° 4' 32.7" North Latitude and 78° 47' 43.87" East to 78° 51' 35.95" East Longitude. The slope maps of the study area derived from SRTM and ASTER DEMs are shown in [Fig-1] and [Fig-2].

The study aims to compare the slope length algorithms. Two criteria were chosen for comparing different algorithms. The Criteria-I consists of 4 different elevation classes with elevation ranging from 77.0 - 91.0 m, 91.0 m – 101.0 m, 101.0 – 112.0 m and 112.0 -139.0 m for class I, II, III and IV respectively. Criteria–II consists of two slope classes with slope percent ranging from 0 – 9% and above 9% for Class-I and Class-II respectively. In the present study topographic survey using total station was adopted for the validation of dataset.

Results and Discussion

The minimum, maximum, mean and SD (standard deviation) values of L-factor derived under different scenarios using SRTM and ASTER DEMs are shown in [Table-1] and [Table-2].

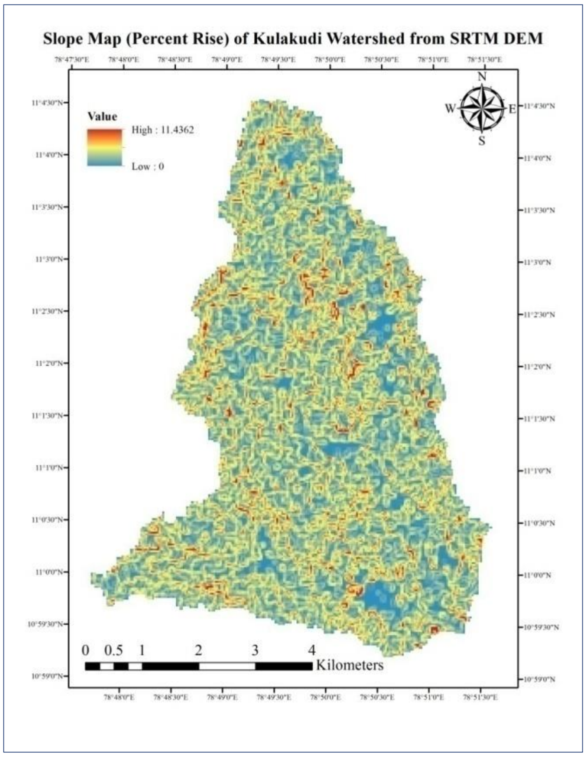

Fig-1 Slope (Percent Rise) Map from SRTM DEM

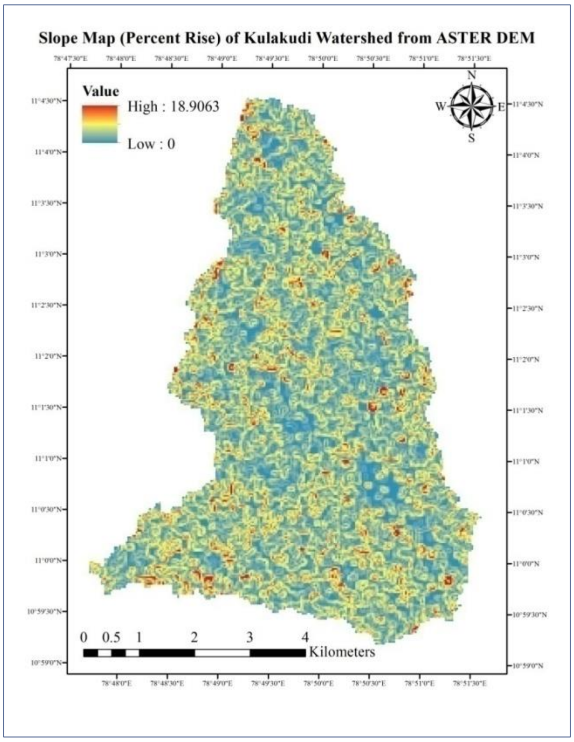

Fig-2 Slope (Percent Rise) Map from ASTER DEM

Fig-1-2 Slope Maps of Kulakudi Watershed from SRTM and ASTER DEMs

Table-1 *Statistical Parameters of L-Factor derived from SRTM DEM*

Erosion Model	L-Factor	Minimum	Maximum	Mean	SD
USLE	L-CSL	0	96.79	2.8	3.87
	L-SCA	0.98	162.34	2.4	3.85
RUSLE	L-CSL	0	53.01	2.1	2.71
	L-SCA	0.98	79.14	1.77	1.83

Table-2 *Statistical Parameters of L-Factor derived from ASTER DEM*

Erosion Model	L-Factor	Minimum	Maximum	Mean	SD
USLE	L-CSL	0	137.01	3.53	5.45
	L-SCA	0.82	397.72	2.4	6.03
RUSLE	L-CSL	0	114.52	2.62	3.97
	L-SCA	0.79	186.91	1.94	3.65

The relative errors obtained between CSL and SCA methods in USLE and RUSLE models were shown in [Fig-3.1] to [Fig-3.4] for slope class-I and [Fig-4.1] to [Fig-4.4] for slope class-II respectively**.** The 1:1 linear line represents the demarcation of the values obtained from the two methods. From the graphs it can be inferred that the L-factor values derived from SCA method is having less error against CSL methods in the study area. The shape of the upslope area is the important factor in the determination of the L-factor values by CSL and SCA methods. The contour length exponent in addition to slope length exponent influences the results from SCA method.

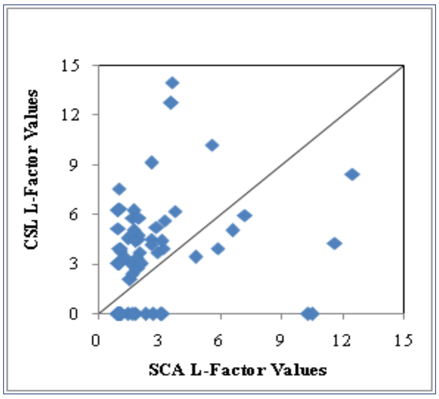

Fig-3.1-USLE-SRTM

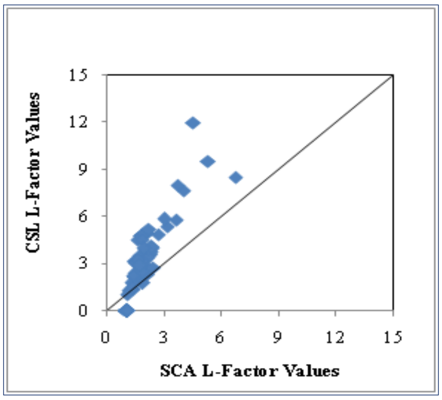

Fig-3.2-RUSLE-SRTM

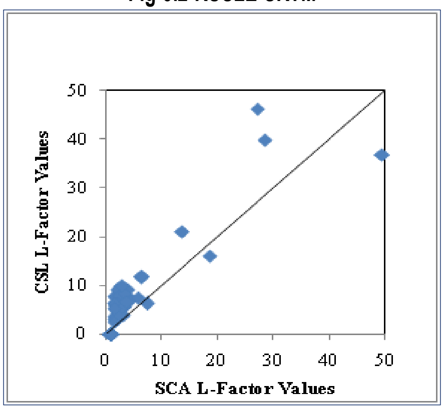

Fig-3.3-USLE -ASTER

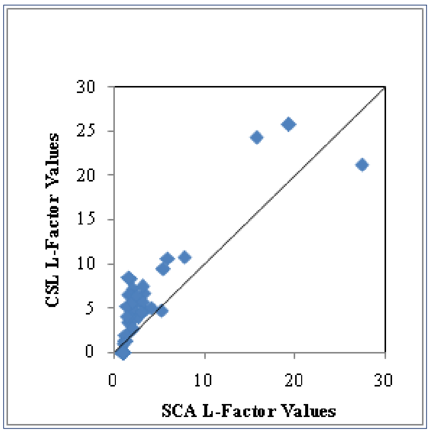

Fig-3.4-RUSLE-ASTER

Fig-3.1-3.4-Comparison of SCA and CSL Methods using sample points in Slope Class-I for SRTM and ASTER DEMs

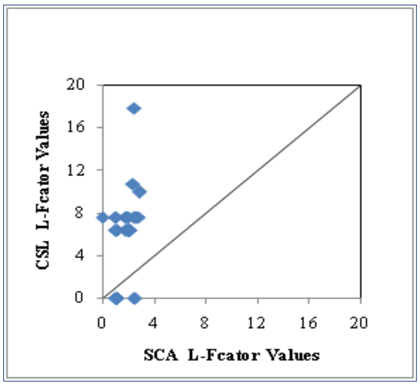

Fig-4.1- USLE-SRTM

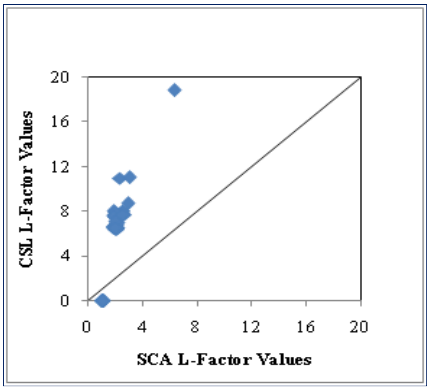

Fig-4.2-RUSLE-SRTM

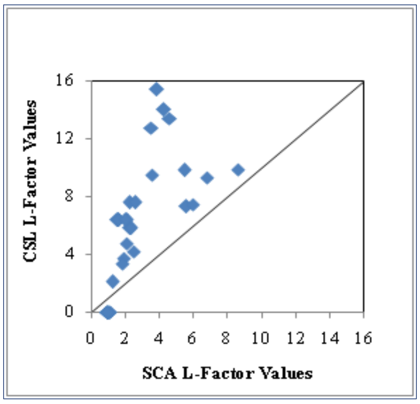

Fig-4.3-USLE-ASTER

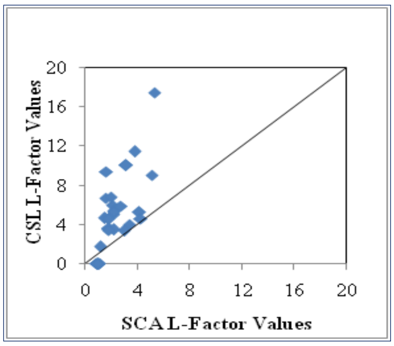

Fig-4.4- RUSLE-ASTER

Fig-4.1–4.4- Comparison of SCA and CSL Methods using sample points in Slope Class-II for SRTM and ASTER DEMs

It was reported that the SCA method is giving greater values over CSL method in different landforms in Loess Plateau, China except for table land areas [4]. This is due to the reason that near the ridgelines the flow direction will be usually diagonal, hence contour length exponent values reaches higher values leading to smaller SCA values. In the case of present study area, diagonal flow direction occurs in about 21% of the pixels in SRTM DEM and about 19.7% pixels in ASTER DEM; hence the contour length exponent effect is minimized. This may lead to approximate predictions of slope length values in the study area by the SCA method.

In both the methods the flow direction plays the vital role and it has been calculated based on D8 algorithm in the present study. Also the edge cells were not excluded from processing. The D8 flow direction algorithm is found to be simplifying the flow process. Hence it is important to incorporate multiple flow path methods to approximate flow on sub-grid scale in standard GIS packages.

Effect of Slope Length Exponent on Derivation of L-Factor

In the present study as per SRTM derived slope percentage map, slope percent exceeds 5%. Hence, a comparison on L-factor values obtained through single exponent m=0.5 and pixel to pixel varying slope length exponent values was done adopting USLE and RUSLE model recommendations. The [Fig-5] and [Fig-6] shows the difference obtained in L-factor values under the two scenarios in test sites of slope class-I.

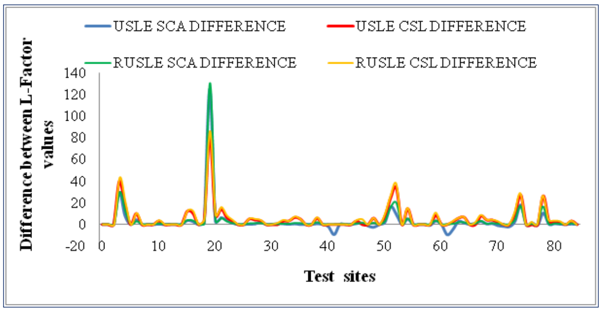

Fig-5 The difference in L-Factor values between m = 0.5 and pixel to pixel 'm' values in SRTM DEM dataset

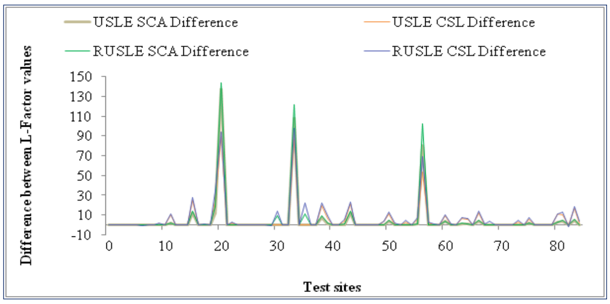

Fig-6 The difference in L-Factor values between m=0.5 and pixel to pixel 'm' values in ASTER DEM datasets

From the graph it is clear that there is no correlation between L-factor values obtained through the two scenarios. In majority of the test points, both the methods under USLE and RUSLE model over predicts the L values with m=0.5. The maximum over estimates observed were 130.4%, 124.99%, 85.75% and 3.645 for RUSLE-SCA, USLE-SCA, RUSLE-CSL and USLE-CSL respectively at several locations in SRTM DEM. The corresponding values in ASTER DEM are 143.8%, 137.685, 97.8%, and 89.08% respectively. The results show that the pixel to pixel approach in slope length exponent is justifiable under low slope (<5%) conditions. For hilly terrains the results may be contradictory, where adoption of a single exponent value, mayn't makes any difference in derived L values as most part of the terrain comes under >5% scenario.

Conclusions

Slope length factor is one of the most important factors in empirical soil loss estimation models. There are different approaches for estimation of slope length factor within the GIS platform. The aim of the present study is to compare the specific contributing area method and cumulative slope length method in a gently sloping terrain using SRTM as well as ASTER DEMs with 30 m resolution. The result suggested that SCA method should be adopted for gently sloping terrains since the contour length exponent effect on the algorithm get minimized due to minimum diagonal flow direction. Also, the slope length exponent value should be based on pixel to pixel variation in slope classes, otherwise the slope length predictions will get overestimated. The results of the study may vary depending upon the terrain characteristics and will aid in soil erosion assessment studies over gently sloping terrains. The same kind of studies are not yet conducted and verified in gently sloping terrains.

Acknowledgement

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Application of Research

Slope Length is an important factor USLE erosion model and its revised versions. The results of the present study give insights into appropriate estimation of soil erosion in gently sloping terrains by adopting specific contributing area method within GIS platform. The adoption of slope length algorithms according to terrain characteristics is not refined yet.

Author Contributions

*1 and 2 conceived the methodology for the study. 3 and 4 analyzed the data and results*1 wrote the paper.

Abbreviations

AEC & RI	Agricultural Engineering College and Research Institute
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CAE	College of Agricultural Engineering
CSL	Cumulative Slope Length
DEM	Digital Elevation Model
Eq.	Equation
et al	And others
etc.	et cetera
GIS	Geographic Information System
ha	Hectare
km	Kilo Meter
L	Slope Length Factor
m	Slope Length Exponent
mm	Milli Meter
NCSL	Non Cumulative Slope Length
RUSLE	Revised Universal Soil Loss Equation
S	Slope Steepness Factor
SCA	Specific Contributing Area
SRTM	Shuttle Radar Topography Mission
TNAU	Tamil Nadu Agricultural University
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
USPED	Unit Stream power Erosion and Deposition
viz.	Namely
θ	Slope Angle (Degrees)
λ	Horizontal Slope Length
SD	Standard Deviation

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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