DEM based Extraction of LS factor: integrate channel networks and convergence flow

Hongming Zhang
College of Information and Engineering
Northwest A&F University
Yangling,Shaanxi 712100 China
zhm@nwsuaf.edu.cn

Qinke Yang*
Department of Urbanology and Resource Science
Northwest University
Xi'an, Shaanxi, 710069, China
qkyang@126.com

Shuqin Li
College of Information and Engineering
Northwest A&F University
Yangling,Shaanxi 712100 China
lsq_cie@nwsuaf.edu.cn

Wenting Han
College of Mechanical and Electronic Engineering,
Institute of Water Saving Agriculture in Arid Regions of China, Northwest A&F University
Yangling,Shaanxi 712100 China
hanwt2000@126.com

Shangshang Yu
College of Information and Engineering
Northwest A&F University
Yangling,Shaanxi 712100 China
yushangshang@nwsuaf.edu.cn

Xiaoyan Zhao
College of Information and Engineering
Northwest A&F University
Yangling,Shaanxi 712100 China
zhaoxiaoyan@nwsuaf.edu.cn

Abstract—**LS is a very important factor in erosion evaluation. Slope gradient and slope length is used to calculate LS factor. However a major limitation is the difficulty in extracting the LS factor at regional landscape scales. The geographic information system-based (GIS-based) methods which have been developed for estimating the slope length for USLE and RUSLE model also have limitations. he unit contributing area-based estimation method (UCA) converts slope length to unit contributing area for considering two-dimensional topography, however is not able to predict the different zones of soil erosion and deposition. The flowpath and cumulative cell length-based method (FCL) overcomes this disadvantage but does not consider channel networks, flow convergence and divergence flow in three-dimensional topography. The purpose of this research was to overcome these limitations and extend the FCL method through inclusion of channel networks, convergence and divergence flow. We developed LS-TOOL in Microsoft's .NET environment using C# with a user-friendly interface. Comparing the LS factor calculated with the three methodologies (UCA, FCL and LS-TOOL). LS-TOOL delivers improved results. In particular, LS-TOOL uses breaks in slope identified from the DEM to locate soil erosion and deposition zones, channel networks, convergence and divergence flow areas. Slope length and LS factor values generated using LS-TOOL correspond more closely with the reality of the Xiannangou catchment than results using UCA or FCL. The LS-TOOL algorithm can automatically calculate slope length, slope steepness, L factor, S factor, and LS factors, providing the results as ASCII files which can be easily used in some GIS software. This study is an important step forward in conducting accurate large-scale erosion evaluation.**

I. INTRODUCTION

Topographic is an important factor in erosion evaluation. Slope gradient and slope length are often used to estimate topographic factor. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978)and Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) are the most commonly used equation to estimate soil erosion despite their shortcomings and limitations. In these equations, the slope length factor and slope gradient factor terms of the equation are generally lumped together as "LS" and the effect of topography on erosion is accounted for by the dimensionless LS factor. We often call LS as topographic factor.

Slope length for these equations are defined as "the distance from the point of origin of overland flow to either of the following, whichever is limiting for the major part of the area under consideration: (a) the point where the slope decreases to the extent that deposition begins, or (b) the point where runoff enters a well-defined channel that may be part of a drainage network or a constructed channel such as a terrace or diversion". Therefore, there are two conditions caused slope length break, one is slope which decreases enough, and the other is channel. (Wischmeier and Smith 1978)

Because of the watershed erosion models are under developing, many researchers applied the USLE and RUSLE to estimate soil loss in watershed estimations for the simple, robust form of the equations to their success in predicting the average, long-term erosion on uniform slopes or field units. Traditionally, the best estimation methods for slope length are obtained from field measurements, but these are not always available or practical, especially at large areas or watersheds.

Moore and Wilson (1992) presented a simplified equation using unit contributing area (UCA) for calculating the LS factor over the three-dimensional terrain. Desmet and Govers (1996) used a multiple-flow direction （MFD） algorithm developed by Quinn *et al.* (1991) to calculate contributing areas, then to calculate the LS factor in segments. Winchell *et al.* (2008) improved Desmet and Govers (1996) method and compared several variations of the GIS approach to come up with a better method. The major limitation of these methods is the absence of an algorithm for predicting topographically-driven zones of soil deposition.

Consequently new models have been developed to overcome this disadvantage. One approach for identifying breaks in slope length involves the evaluation of change in slope based on the concept of slope length as proposed by Dunn and Hickey (1998), Hickey (2000) and Van Remortel et al. (2001). The ArcInfo Arc Macro Language (AML) program for creating a USLE/RUSLE–based LS factor grid from an input digital elevation model (DEM) dataset was based on this approach. Later, Van Remortel et al. (2004) focused on the mechanisms involved in extracting key flowpath-based and cumulativing cell length portions (FCL) of the original AML program.. SFD algorithm allows only parallel and convergence flow, while MFD method can accommodate divergent flow and have a better performance of real terrain than SFD algorithm (Wilson *et al.* 2007). However, it's a very complex procedure while using MFD algorithm to calculate slope length with cutoff conditions considered, even it's better than SFD method. Therefore, it is inevitable to cause some inaccuracies by these recent models.

The aim of this paper is to propose an algorithm that extends the FCL method and revise its calculation algorithm for slope length. Using the concept of the MFD algorithm with a focus on the calculation of slope length including slope changes and channel networks, a calculation process is shown in Figure 1. A comparison of results for slope length and LS factor calculated by the UCA, FCL and LS-TOOL method (this paper) for Xiannangou catchment is presented.

II. MATERIALS AND METHODS

A. *The model theory*

Moore and Burch (1986a, b) recognized that higher erosion or deposition rates occured at the convergence of a catchment as also postulated in the USLE/RUSLE. These results have implied that sheet flow has the lowest sediment transport capacity and that the topographic convergence or divergence in a catchment can increase or decrease the unit stream power and the sediment transport capacity. Zhang *et al.* (2013) extended the FCL method and revises its calculation algorithm for slope length and flow convergence both based on the UCA algorithm as well as the cutoff conditions for including channel networks. The equations to calculate the slope length are as follows:

$$\lambda_{i,j} = \sum_{x=0,y=0}^{x=i,y=j} \sum_{k=1}^{m} CSL_{x,y} \qquad (1)$$

CSL= cell slope length of coordinates(x,y)

$\lambda_{i,j}$ =the slope length of coordinates (i,j)

k=the code of the surrounding eight cells of coordinates(x,y)

Here we extended the equations of Zhang *et al.* (2013), so we still call slope length as distributed watershed erosion slope length (DWESL). According to the equation, if we use the MFD algorithm, CSL will be decided by slope aspect. For the least sensitive to the DEM data error (Zhou and Liu 2004), the third-order finite difference (3FD) algorithm (Wood 1996) was used to calculate slope aspect and slope gradient. How to calculate CSL and DWESL using MFD algorithm is described in the following section.

B. *The model structure*

The methodology for calculating the slope length, slope steepness, L and S factor is illustrated in Figure 1, which shows an overall view of the process:

Step 1: Input data from a DEM data,

Step 2: Analyze the DEM data to determine if suitable data is available to use in the model,

Step 3: If the DEM data is available, fill any spurious single-cell nodata cells and sinks within the source DEM data by using an iterative routine,

Step 4: Use 3FD method for estimation of slope angle and slope aspect, Step 5: Calculate cell downhill outflow portion (outflow direction) and cutoff direction for the each individual direction by using the MFD algorithm,

Step 6: Calculate the cell slope length (CSL) by using slope aspect,

Step 7: Use a forward-and-reverse traversal method to compute contributing area,

Step 8: Calculate DWESL using outflow portion data, cell slope length data, and contributing area threshold value,

Step 9: Determine L factor by using DWESL, and length-slope exponent,

Step 10: Calculate S factor constituent using the slope angle,

Step 11: Compute the LS factor.

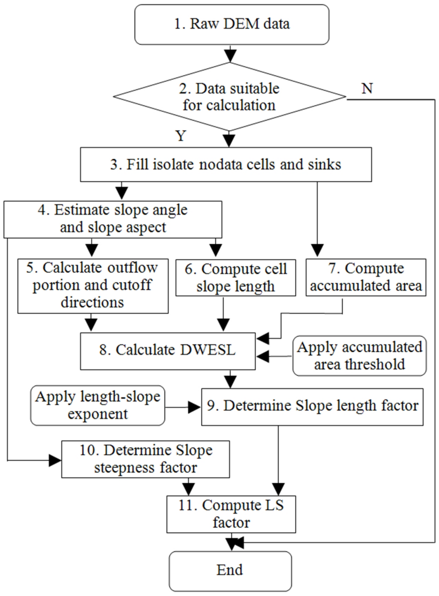


Figure 1. Flowchart illustrating the process of calculating LS factor

C. Comparison of the model

In order to compare LS-TOOL with existing methods, we applied the three GIS methods in Xiannangou catchment, Shaanxi province, China (Figure 2). The comparison focused on operating of the model.

The three GIS methods, UCA (Moore and Wilson, 1992), FCL (Van Remortel et al., 2004) and LS-TOOL were compared by calculating the slope length and LS values.

With the UCA, because there is an upper bound to the slope length which usually does not exceed 1000 feet (304.8m) (Renard et al., 1997). we chose to use equation (2) (p=0.4, q=1.3) following Jabbar's approach (2003), with a maximum accumulation of 60 grid cells, and using the spatial analyst tools in ArcGIS.

The FCL method was implemented using C++ program (Van Remortel et al., 2004).

In applying of LS-TOOL, we selected an accumulated area threshold of 40 00m^2, because this threshold corresponded well to the real channels. LS-TOOL is developed in Microsoft's .NET environment using C#.

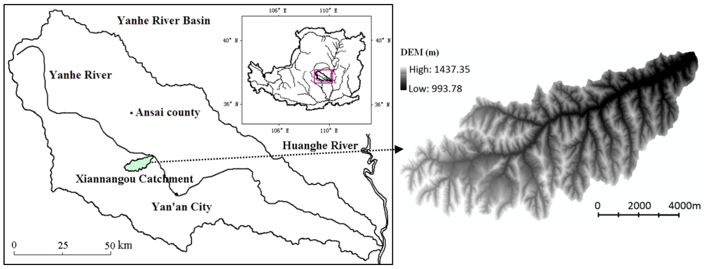


Figure 2. The left main map shows the location of the Xiannangou catchments (light green shading) in the Loess Plateau in the middle reaches of the Yellow River basin. The inset map shows the location of the Loess Plateau in the middle reaches of the Yellow River basin, China. The right map shows the 5 m DEM of the study site.

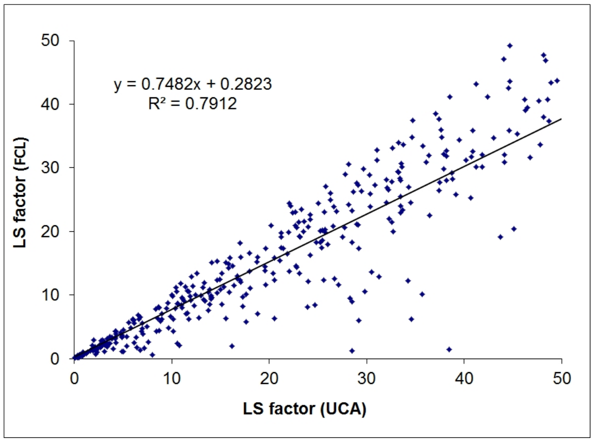
III. RESULTS AND DISCUSSION

A. Statistical analysis of slope length and LS factor value

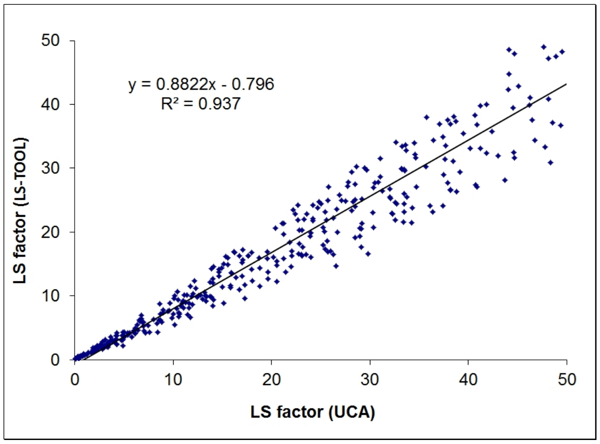
DWESL value calculated by LS-TOOL$_{\text{MFD}}$ is a normal distribution, 66.2% of the DWESL is less than 80 meters, 80.5% of the DWESL less than 120 meters, 93.6% of the DWESL less than 300m (Figure 3a). LS factor value is also normal distribution, 99.4% of LS factor value is less than 72, 87.2% LS factor value less than 30, and 52.1% LS value is between 7 and 22 (Figure 3b). These results coincide with the LS factor value in McCool's findings (McCool *et al.*, 1997).

B. Comparison of LS factor values-correlation to UCA

We compared the calculated LS-values based on the UCA approach to those generated with FCL and LS-TOOL, by using 50 randomly selected cells and the upslope cells to the start of the slope lengths (total 406 cells). The linear regression r^2 and regression line LS values for this evaluation are shown in Figure 3a (FCL) and 3b (LS-TOOL). An important objective of this study was to gain an understanding of how the existing GIS-based LS-factor values estimation methods compare with LS-TOOL. It can be seen that the distribution of LS-factor values estimated using the LS-TOOL correlates more closely to those approximated by the UCA method. As the slope gradient increased, the differences of LS factor values also increased. There is clearly a stronger correlation between the UCA method and LS-TOOL at lower slope gradients.



(a) FCL method



(b) LS-TOOL method

Figure 3. Comparison of LS factors with UCA method.

ACKNOWLEDGMENT

The first author would like to express great appreciation to Demie Moore for language edition. Thanks to Lei Wang, Weiling Guo, Chunmei Wang, Jun Li and Lanqin Guo from Institute of Soil and Water Conservation, for providing helpful comments on an earlier draft of this manuscript. Thanks to Chen Yan, Xian Chen, Jie Zhang and Jinxiang Wang from the Northwest A&F University for their useful discussions and suggestions in coding work. This research was supported by the " Five-twelfth" National Key Technology R&D Program (2012BAH29B04), Chinese National Natural Science Foundation (41301283, 41071188) and Fundamental Research Funds (QN2013051, ZD2012018) of Northwest A&F University. Thanks also to the anonymous reviewers and special issue editors who all made valuable comments that improved our paper.

REFERENCES

[1] Desmet, P.J.J., Govers, G., 1996. A GIS procedure for the automated calculation of the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation (51), 427-433.

[2] Dunn, M., Hickey, R., 1998. The effect of slope algorithms on slope estimates within a GIS. Cartography 27(1), 9-15.

[3] Hickey, R., 2000. Slope Angle and Slope Length Solutions for GIS. Cartography 29(1), 1-8.

[4] Moore, I.D., Burch, G.J., 1986a. Modelling Erosion and Deposition: Topographic Effects. Transactions of the American Society of Agricultural Engineers 29(6), 1624-1630.

[5] Moore, I.D., Burch, G.J., 1986b. Sediment Transport Capacity of Sheet and Rill Flow: Application of Unit Stream Power Theory. Water Resources Research 22(8), 1350-1360.

[6] Moore, I.D., Wilson, J.P., 1992. Length-slope factors for the revised universal soil loss equation: simplified method of estimation. Journal of Soil & Water Conservation 47(5), 423-428.

[7] Quinn, P., Beven, K., Chevallier, P., Planchon, O., 1991. The prediction of hillslope flow paths for distributed hydrological modelling using digital terrain models. HYDROLOGICAL PROCESSES 5(1), 59-79.

[8] Renard, K.G., Foster, G.R., Weeies, G.A., 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation(RUSLE). Agriculture Handbook, 703, Washington D. C.: U.S. Department of Agriculture

[9] Van Remortel, R.D., Hamilton, M.E., Hickey, R.J., 2001. Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data. Cartography 30(1), 27-35.

[10] Van Remortel, R.D., Maichle, R.W., Hickey, R.J., 2004. Computing the LS factor for the Revised Universal Soil Loss Equation through array-based slope processing of digital elevation data using a C++ executable. Computers & Geosciences 30(9-10), 1043-1053.

[11] Wilson, J.P., Lam, C.S., Deng, Y., 2007. Comparison of the performance of flow-routing algorithms used in GIS-based hydrologic analysis. HYDROLOGICAL PROCESSES 21(8), 1026-1044.

[12] Winchell, M.F., Jackson, S.H., Wadley, A.M., Srinivasan, R., 2008. Extension and validation of a geographic information system-based method for calculating the revised universal soil loss equation length-slop factor for erosion risk assessments in large watersheds. Journal of Soil and Water Conservation 63(3), 105-111.

[13] Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses : A guide to conservation planning with Universal Soil Loss Equation (USLE) Agriculture Handbook. Washington,D C: Department of agriculture, No 703.

[14] Wood, J.D., 1996. The Geomorphological Characterisation of Digital Elevation Models. University of Leicester, UK.

[15] Zhang, H., Yang, Q., Li, R., Liu, Q., Moore, D., He, P., Ritsema, C.J., Geissen, V., 2013. Extension of a GIS procedure for calculating the RUSLE equation LS factor. Computers & Geosciences 52(0), 177-188.

[16] Zhou, Q.M., Liu, X.J., 2004. Error Analysis on Grid-Based Slope and Aspect Algorithms. Photogrammetric Engineering & Remote Sensing 70(8), 957-962.