Study on the Distributed Slope Length for Soil Erosion Prediction at Watershed Scale

Yang, Q. K., [1,2] Zhang, H. M.,[3] Wang, C. M. [1], Zhao M. D.,[1] Liu Y. M.[1] Wang, L.[1]

(1. College of Urban and Environment, Northwest University, Xi'an , Shaanxi, China; 2. Institute of Soil and Water Conservation Chinese Academy of Sciences Ministry of Water Resources, Yangling, Shaanxi, China; 3. College of Information Engineering, Northwest A & F University Yangling, Shaanxi, China)

Abstract—As the most mature and practical soil erosion prediction models so far in the world, USLE and its derivative models, including RUSLE and CSLE, have been widely applied in the soil erosion inventory and mapping at watershed and regional scale. In the models the impacts of terrain on soil erosion is represented by Length Slope factor (LS), which calculate based on DEM derived slope degree and slope length layers. The extraction of slope and slope length themes, especially the latter, of a watershed for each location is difficulty and key issue in the application of USLE to soil erosion assessment and mapping at watershed and regional scale. The issues reviewed and discussed in this paper include; (1) slope length (USLE slope length), at the slope scale, for soil erosion prediction is a specified term introduced by USLE to represent the influence of slope length to sheet and rill erosion, so the slope length is different from similar concepts in geomorphology and hydrology which is really a flow length in hydrology. (2) Slope length of the distributed basin soil erosion (watershed slope length, in short, WSL) refers to the slope length of erosion of any point within the basin that is consistent with the process of erosion, transportation and settlement of the slope soil within the basin when actual topographical conditions of the basin are taken into consideration; (3) The WSL is an extension of USLE slope length from hill slope to a compound terrain parameter in 3-D dimensional landscape, and orient to the USLE application directly in soil erosion survey and mapping. (4) There are 4 algorithms proposed by researchers, and there are more or lees differences between them, of which the cumulative runoff algorithm by Hickey and Van Remortel is much better than others. (5) the extraction of WSL is mainly influenced by four factors, including DEM resolution, flow direction algorithm, partitioning strategy of DEM datasets, and cut-off methods of slope length; (6) The issues should be further studied include principles and software tools for WSL extraction, variance structures and statistical distribution, uncertainties and applicability analysis of the WSL in the soil erosion study at watershed and regional scale.

Key words—USLE, distributed slope length, DTA, GIS

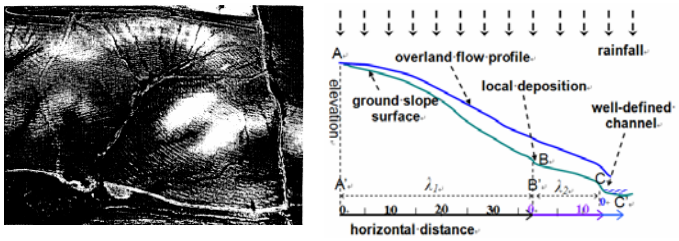
1 INTRODUCTION

As the most popular soil erosion assessment model, USLE (and RUSLE, CSLE) has been used widely in watershed and regional scale soil erosion survey and mapping[1-5] . The influence of terrain to soil erosion was measured by length slope factor (LS factor for short) witch calculated on slope length and slope gradient[6-8]. And the calculation of slope length based on DEM is one of the difficult questions for the application of USLE in soil erosion survey and mapping at watershed and regional scale. In this paper, slope length at watershed scale discussed systematically, including the concept of distributed slope length for soil erosion prediction at watershed scale (watershed slope length, WSL for short), extraction method, and it's influence factors , in order to improve the calculation method of WSL and boost the study on quantitatively soil erosion assessment and modeling at watershed scale.

2 CONCEPT OF DISTRIBUTED SLOPE LENGTH FOR SOIL EROSION PREDICTION AT WATERSHED SCALE

2.1 Concept of Slope Length for Soil Erosion Prediction

In soil erosion research, slope length is the horizontal distance from the source of runoff to a deposition place where slope decrease to some degree or to an well-defined channel (including nature and man-made channel) [14]. In field survey, it is measured through several typical profiles[7].As in Fig.1, the distances from A′ to B′ and B′ to C′ (λ_1 and λ_2) refers to slope length for soil erosion prediction. And the distance from A′ to any point between A′ and B′ or the distance from B′ to any point between B′ and C′ refers to distributed slope length for soil erosion prediction at watershed scale.



a. slope land[7] b. slope length of hill slope scale[15]

Fig. 1 concept of slope length in USLE

2.2 Concept of Distributed Slope Length for Soil Erosion Prediction at Watershed Scale

In order to use USEL at larger scale, some research should be taken on LS factor at watershed scale [9-11, 13, 16]. According to these researches, the distributed slope length for soil erosion prediction at watershed scale is suitable to the process of soil erosion -- transportation --deposition in watershed and could be calculated at any point in the watershed[17] (Fig. 2 & Fig. 3). In some researchers' options, it could be taken place by specified catchments area [10, 13, 18].

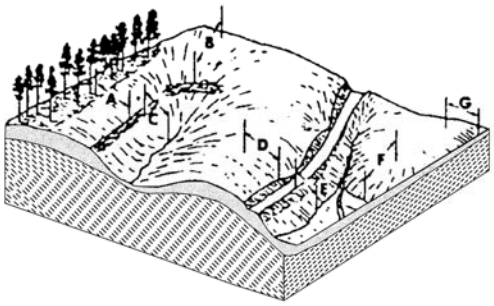


Fig. 2 concept of WSL (Wilson, 1986）

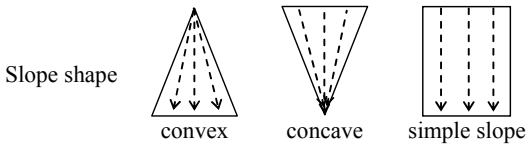


Fig. 3 slope shape and slope length

3. Algorithms of Distributed Slope Length for Soil Erosion Prediction at Watershed Scale

Varied algorithms of slope length had been developed according to varied understanding of slope length, including the simplified algorithm proposed by Tang[19, 20], Hickey's cumulative runoff algorithm[21, 22], the algorithm based As[10, 13, 23], algorithm based on flow length[24] , and the method based on classification of terrain proposed by Gallant[25]. The differences among the varied algorithms are shown in Fig.4. And Hickey's algorithm seems to be better. In order to calculate distributed slope length for soil erosion prediction at watershed scale, the authors developed a software named LS_Tool based on algorithms proposed by Hickey and van Remortel [21, 22], and partial code provided by Remortel.

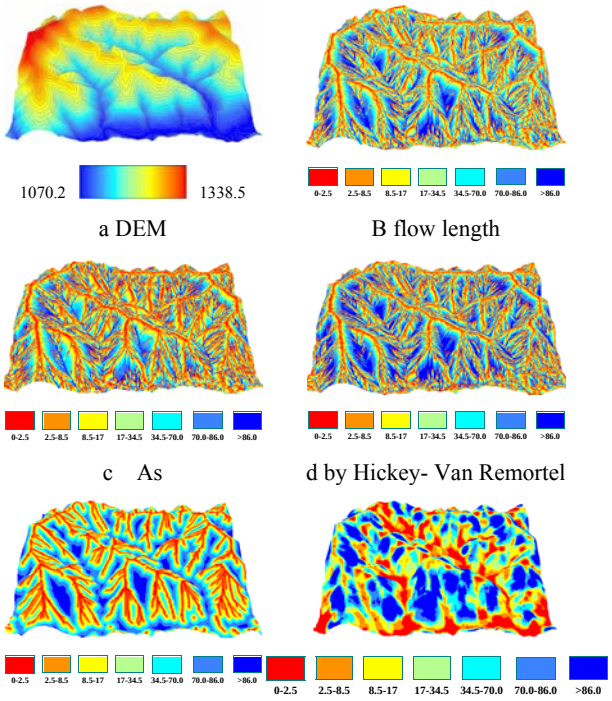


Fig. 4 simple comparisons of SWL algorithms

4. Impact Factors of Distributed Slope Length for Soil Erosion Prediction at Watershed Scale

The studies show that, the extraction of WSL was mainly influenced by resolution of DEM[27-29] , flow direction algorithm[26] and slope length cut off methods. With resolution became coarser, WSL increased. And WSL based on single flow direction algorithm is shorter than that based on multiple flow direction algorithm, and the variance of surface is larger than the latter (Tab.1).

Tab.1 Relationship between terrain parameters and flow direction algorithms[26]

terrain parameters	mean	variance
single flow direction algorithm		
As (m^2/m)	287.15	30.27
multiple flow direction algorithm		
As (m^2/m)	354.25	24.05

5. About Further Studies

Considering the importance of WSL in soil erosion assessment and mapping, several topics should be researched in the future, including algorithms of WSL, spatial and statistic characteristics of WSL, uncertainties of WSL and the applicability analysis of WSL.

ACKNOWLEDGMENT

This research was supported by Natural Science Foundation of China project (Estimating Spatially Distributed Slope Length at Watershed for Soil Erosion Assessment41071188; and Re-scaling of Slopes Derived from Lower Resolution DEMs for Regional Soil Erosion Modeling, 40971173）

REFERENCES

[1]Lu, H., Prosser, I. P., Moran, C. J., Gallant, J. C., Priestley, G., Stevenson, J. G. Predicting sheetwash and rill erosion over the Australian continent [J]. Australian Journal of Soil Research, 2003, 41(6): 1037-1062.

[2]Yang, D., S. Kanae, T. Oki, T. Koike, K. Musiake. Global potential soil erosion with reference to land use and climate changes [J]. Hydrological Processes, 2003, 17: 2913-2928.

[3]Hammad, A. A. Watershed erosion risk assessment and management utilizing revised universal soil loss equation-geographic information systems in the Mediterranean environments [J]. Water and Environment Journal, 2009, 25(2): 149-162.

[4]CHENG Lin,YANG Qinke,XIE Hongxia,WANG Chunmei,GUO Wei-ling.GIS and CSLE Based Quantitative Assessment of Soil Erosion in Shaanxi ,China [J]. Journal of Soil and Water Conservation, 2009, 23(5): 61-66.

[5] XIE Hongxia, LI Rui, YANG Qinke, LI Jing,LIANG Wei. Effect of Returning Farmland to Forest (Pasture) and Changes of Precipitation on Soil Erosion in the Yanhe Basin[J]. Scientia Agricultura Sinica, 2009, 42(2): 569-576.

[6]Wischmeier, W. H., Smith, D. D. Predicting rainfall eosion losses: A Guide to conservation planning [M]. USDA Agric. Handb. No 537, 1978.

[7]Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., Yoder D. C. , et al. Predicting rainfall eosion by Water: A Guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE) [M]. In: USDA Agric. Handb. No 703 [M] 1997.

[8]Liu, B. Y., Zhang, K. L., Xie, Y. A empirical soil loss equation [M]. In: Process of soil erosion and its environment effect volume Ⅱ 12th ISCO [M]Beijing: Tsinghua press, 2002. 143-149.

[9]Williams, J. R., Berndt, H. D. Determining the universal soil loss equation's length-slope factor for watersheds [M]. In: Soil Erosion: Prediction and Control [M], Foster, G. R., Editor: Soil Conservation Society of American, Iowa, 1977. 217-225.

[10]Moore, I. D., Burch, G.J. Physical basis of the length-slope factor in the Universal Soil Loss Equation [J]. Soil Science Society of America Journal, 1986, 50(5): 1294-1298.

[11]Wilson, J. P. Estimating the topographic factor in the universal soil loss equation for watersheds [J]. Journal of Soil and Water Conservation, 1986, 41(3): 179-184.

[12]Griffin, M. L., Beasley, D. B., Fletcher, J. J., Foster, G. R. Estimating soil loss on topographically nonuniformed field and farm units [J]. Journal of Soil and Water Conservation, 1988, 43(4): 326-331.

[13]Moore, I. D., Wilson, J.P. Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation [J]. Journal of Soil and Water Conservation, 1992, 47(5): 423-428.

[14]Smith, D. D., Wischmeier, W. H. Factors affecting sheet and rill erosion [J]. American Geographer Union Trans, 1957, 38: 889-896.

[15]Horton, R. Erosional Development of Streams and Their Drainage Basin; Hydrophysical approach to quantitative morphology [J]. Geological Society of America Bulletin, 1945, 56(3): 275-370

[16]Rodríguez, J. L., G., 1 and Martín C. Giménez Suárez2 Estimation of Slope Length Value of RUSLE Factor L Using GIS [J]. Journal of Hydrologic Engineering, 2010, 15(9): 714-717

[17]YANG Qinke,GUO Weiling,ZHANG Hongming,WANG Lei,CHENG Lin,LI Jun. Method of Extracting LS Factor at Watershed Scale Based on DEM [J]. Bulletin of Soil and Water Co nserv atio n, 2010, 30(2): 203-206.

[18]Moore, I. D., Wilson, J.P. Reply to comments by Foster on “Length-slope Factors for the Revised Universal Soil Loss Equation: Simplified Method of Estimation” [J]. Journal of Soil and Water Conservation, 1994, 49(5): 174-80.

[19]TANG Guoan，CHEN Zhengjiang，ZHAO Mudan，LIU Wanqing，LIU Yongmei. The Spatial analysis Method of GIS Based on ARCVIEW [M]. Beijing: Science Press, 2004. p174-175.

[20]CAO Longxi, FU Suhua. A Comparison of Methods for Computating Slope Length Based on DEM [J]. Bulletion of Soil and Water Conservation, 2007, 27(5): 58-62.

[21]Hickey, R., Smith, A., Jankowski, P. Slope Length Calculations from a DEM Within ARC/INFO GRID [J]. Computers, Environment and Urban Systems, 1994, 18(5): 365-380.

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

[23]Desmet, P. J. J., Govers G. A GIS procedure for automatically calculting the USLE LS factor on topographically complex landscape units [J]. Journal of Soil and Water Conservation, 1996, 51(5): 427-433.

[24]JIN Bei,LIU Xuejun,ZHEN Yan,LI Haoshu. Analysis of Slope Length Extracted from Grid-based Digital Elevation

Model in ArcGIS Environment [J].JOURNAL OF GEO-INFORMATION SCIENCE,, 2010, 12(5): 700-706.
[25]Gallant, J. Terrain scaling for the Continental Scale Soil Erosion Modeling [C]. In: Proceedings of MODSIM 2001: International Congress on Modelling and Simulation. Canberra, Australia: Modelling and Simulation Society of Australia and New Zealand: 925-930. CAnberra. 2001.
[26]Wolock, D. M., McCabe, G. J. . Comparison of Single and Multiple Flow Direction Algorithms for Computing Topographic Parameters in TOPMODEL [J]. Water Resources Research, 1995, 31(5): 1315–1324.
[27]GuoWeiling,Yang Qinke,Cheng Lin,Li Jun. Re-scaling method of slope length factor in the soil erosion assessment of regional scale [J]. Science of Soil and Water Conservati on, 2010, 8(4): 73-78.
[28]Sørensen, R., Seibert, J. Effects of DEM resolution on the calculation of topographical indices: TWI and its components [J]. Journal of Hydrology, 2007, 347(1-2): 79-89.
[29]Pradhan, N. R., Ogden, F. L., Tachikawa, Y., et al. Scaling of slope, upslope area, and soil water deficit: Implications for transferability and regionalization in topographic index modeling [J]. Water resources research, 2008, 44(12): W12421.
[30]Gertner, G. Z. Uncertainty Propagation and Partitioning in Spatial Prediction of Topographical Factor for RUSLE [C]. In: Fourth International Conference on Spatial Uncertainty. Amsterdam. 2000.
[31]Wang, G., Fang, S., Shinkareva, S.,Gertner, G., Anderson, A. Spatial uncertainty in prediction of the topographical factor for the Revised Universal Soil Loss Equation (RUSLE) [J]. Transactions of the ASAE, 2002, 45(1): 109-118.
[32]Wang, G., Gertner, G., Parysow, P., Anderson, A. B. Spatial prediction and uncertainty analysis of topgoraphical factors for the Revised Universal Soil Loss Equation (RUSLE) [J]. Journal of Soil and Water Conservation, 2000, 55(3): 374-384.
[33]Wang, G. X., Gertner, G. Z., Fang, S., Anderson, A. B. A methodology for spatial uncertainty analysis of remote sensing and GIS products [J]. Photogrammetric engineering and remote sensing 2005, 71(12): 1423-1432.