International Soil and Water Conservation Research 5 (2017) 241–251

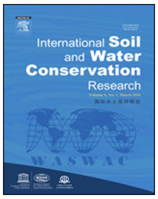
HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr



Original Research Article

The effect of grid size on the quantification of erosion, deposition, and rill network

Xiaoyu Lu [a,*], Yingkui Li [a], Robert A. Washington-Allen [a], Yanan Li [b], Haidong Li [c], Qingwu Hu [d]

[a] University of Tennessee, Department of Geography, 1000 Phillip Fulmer Way, Knoxville, TN 37996, USA
[b] South Dakota State University, Department of Geography, 1021 Medary Ave, Brookings, SD 57007, USA
[c] Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection, Nanjing 210042, China
[d] School of Remote Sensing and Information Engineering, Wuhan University, Wuhan 430079, China

ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form
29 May 2017
Accepted 9 June 2017
Available online 12 July 2017

Keywords:
GIS
Terrestrial laser scanning
Constant drop theory
DEM of difference
Resolution

ABSTRACT

Hillslope rill/interrill erosion has been investigated from the perspective of runoff transport of sediment. Recent advances in terrestrial laser scanning can provide high-resolution elevation data up to centimeter levels, and temporal digital elevation models (DEMs) enabled the detection and quantification of sediment redistribution. Erosion and deposition are spatially heterogeneous across hillslopes, and the choice of resolution is critical when using a DEM to study the spatial pattern of the processes. This study investigates the influence of grid size on the sediment change calculation and rill network delineation based on two surveys using a terrestrial laser scanner on a hillslope with well-developed rills in 2014 and 2015. Temporal DEMs were used to quantify elevation changes and used to delineate rill networks. We produced DEM pairs of incremental grid sizes (1-cm, 2-cm, 5-cm, 8-cm, 10-cm, 15-cm, 20-cm, and 30-cm) for DEM difference and rill network delineation. We used the 1-cm DEM as the reference to compare the results produced from other DEMs. Our results suggest that erosion mainly occurs on the rill sidewalls, and deposition on the rill floors, with patches of erosion/deposition within the interrill areas. Both the area and volume of detectable change decrease as the grid size increases, while the area and volume of erosion are less sensitive compared to those of deposition. The total length and number of rills decrease with the increased grid size, whereas the average length of rills increases. The mean offset between delineated rill network and the reference increases with larger grid sizes. In contrast to the erosion and deposition detected within rills, minor changes are detected on the interrill areas, indicating that either no topographic changes occurred or the changes were too small to be detected on the interill areas by our finest 1-cm DEMs. We recommend to use the finest possible grid size that can be achieved for future studies.

1. Introduction

Water-induced rill/interrill erosion on hillslopes is driven by the impact of rainfall and concentrated surface runoff (Knighton, 1998). During a rainfall event, soil particles may be detached by the raindrop impact and splashed in all directions with a tendency toward the downslope direction. Once the rainfall intensity exceeds the soil's infiltration capability, surface runoff appears, concentrates, and flows towards the foot of the hillslope (Horton, 1945). During this process, rills emerge as micro-channels to dissect the hillslope into rill and interill areas. Rills are the venues to transport sediments detached from both rills and interrill areas through concentrated flow. Rills are micro-relief channels (Knighton, 1998) that are usually <0.3 m in depth and <0.3 m in width (Gao, 2013; Nearing et al., 1997). Rills are usually ephemeral features and can be easily removed by conventional tillage (Haan, Barfield, & Hayes, 1994; Nearing et al., 1997).

Classic approaches for studying hillslope rill/interrill erosion either measure the sediment collected at the bottom of a plot, or compare the changes in surface elevation at different time intervals. The first method collects all or part of the flow and sediment during a period, and measures the weight or the volume

---

Abbreviations: DEM, Digital Elevation Models; TLS, Terrestrial Laser Scanning/Scanner; LiDAR, Light Detection and Ranging; DoD, DEM of Difference; RAPCA, Revised Automated Proximity and Conformity Analysis

[*] Corresponding author.
E-mail address: xlu14@vols.utk.edu (X. Lu).

Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

http://dx.doi.org/10.1016/j.iswcr.2017.06.002

(Stroosnijder, 2005). One limitation of this method is that it only measures the net value of sediment delivery, without accounting for the spatial variability of sediment movement (Boardman, 2006). The second method examines the changes in elevation over an area and/or the channel geometry (usually width and depth), and it is commonly used for areas that are longer than 100 m (such as gullied hillslopes) (Stroosnijder, 2005). The changes in elevation or channel geometry are traditionally measured using erosion pins or tapesat representative sampling locations. This method requires expertise in identifying “representative” locations, and the choice of such locations may be subjective to human bias. The relatively low spatial resolution of data collected using this method is also not sufficient to capture the continuous nature of sediment redistribution.

The development of digital elevation models (DEMs) has led to innovative instrument and software development to detect and quantify the topographic characteristics, such as elevation, slope, profile/curvature, aspect, and roughness (Moore, Grayson, & Ladson, 1991; Pike, 2002; Pike, Evans & Hengl, 2009). Recent advances in remote sensing, particularly the use of terrestrial laser scanning (TLS) systems, have provided elevation measurements of unprecedented accuracy and fine resolution that allow for rapid data collection for three-dimensional (3-D) surface reconstruction and modeling (Heritage & Large, 2009). Various fields have witnessed an increasing trend in applying TLS within multiple disciplines, including geology, glaciology, hydrology, biogeochemistry, and terrestrial ecology (Eitel et al., 2016; Smith, 2015). The point cloud data that is collected by TLS can be directly analyzed for metrics of interest, or converted to a triangulated irregular network (TIN), or raster-based DEMs with resolutions greater than the TLS's laser spot size (usually in mm) and range accuracies of a few millimeters (varied for different scanner systems). The DEM, TIN, or point cloud generated using TLS is suitable for quantifying hydrologic and geomorphic variables of a specific area in a more automatic and flexible fashion (Cavalli, Trevisani, Comiti & Marchi, 2013; Pirotti & Tarolli, 2010; Starek, Mitásová, Wegmann & Lyons, 2013; Tarolli, Sofia, Calligaro, Prosdocimi, Preti & Dalla Fontana, 2015; Vinci, Brigante, Todisco, Mannocchi & Radicioni, 2015).

Many studies have used TLS to investigate rill/interrill erosion in experiment and natural plots (Eltner, Baumgart, Maas, & Faust, 2015; Eltner, Mulsow, & Maas, 2013; Vinci, Brigante, Todisco, Mannocchi, & Radicioni, 2015; Vinci, Todisco, & Mannocchi, 2016, see Table 1). The DEMs produced by TLS can be used to discriminate the spatial pattern of erosion and deposition (Eitel, Williams, Vierling, Al-Hamdan, & Pierson, 2011), derive geomorphometric indices (e.g. surface roughness, in Eitel et al., 2011), and provide high resolution topographic inputs for modeling efforts (Hancock, Crawter, Fityus, Chandler, & Wells, 2008). For example, Eitel et al. (2011) used TLS to test the effect of surface roughness in concentrated flow processes. Vinci et al. (2015) used TLS-produced DEMs to extract rill networks and calculate the rill morphometric characteristics in an experiment plot. They found that TLS has advantages in measuring certain indices (e.g. rill length, eroded volume) compared to manual surveys. Zhang, Tang, Yao, Zhang, & Xizhi (2016) used the TLS-surveyed DEM to quantify rill morphology. Eltner and Baumgart (2015) investigated the accuracy constraints of TLS in a controlled experiment condition and suggested that with the propagated error from multiple sources (including registration, surface roughness, systematic error, and interpolation), the minimal threshold of vertical change detection is 1.5 cm. Hancock et al. (2008) used TLS to produce a DEM of the angle-of-repose of slope in mine spoil for the input of the SIBERIA landscape model.

Some critical issues still exist in TLS-based rill/interrill erosion studies, such as the choice of point spacing at a certain range that is necessary to detect surface features and their changes. A few airborne LiDAR and TLS studies have discussed the effect of DEM grid size on the detection and analysis of land surface features (e.g. Woolard & Colby, 2002), especially the delineation and morphology of rill networks (Vinci et al., 2015; Zhang et al., 2016), but none of these studies have systematically analyzed the effect of grid size on estimation of erosion/deposition and feature geometry in rill/interrill erosion studies. A few studies have observed a resolution threshold that beyond a certain resolution, any finer resolution no longer improves the range accuracy of airborne LiDAR systems (García-Quijano et al., 2008). This threshold effect is also important to TLS systems as the amount of erosion on a hillslope is spatially heterogeneous, and the TLS's ability to detect rill networks and the spatial pattern of erosion/deposition may be limited by the grid size of the observation for these features. A finer resolution may not be a better representation for a type of geomorphic features compared to a coarser resolution, especially when the level of noise (random local variance) is high. On the other hand, a coarser resolution might filter the random local noise, but it is also possible to over-generalize the features of interest, reducing the accuracy of mapping and detecting a certain type of features (Lechner, Jones, & Bekessy, 2008; Lechner, Stein, Jones, & Ferwerda, 2009; Woodcock, 1987).

The effect of TLS point spacing and the grid size of TLS-derived DEMs has been investigated in various water- and erosion-related studies, including erosion modeling (Zhang, Chang, & Wu, 2008), watershed modeling (Yang et al., 2014), and delineation of stream network (Charrier & Li, 2012). The purpose of this study is to assess the effect of DEM resolution on the quantification of hillslope erosion and deposition and on the delineation of rill network through a case study from a rilled hillslope in Loudon, Tennessee, USA. The results of this study provide insights into the determination of an optimal DEM resolution and guidance for future TLS-based erosion studies.

Table 1
Application of TLS for rill/interrill erosion studies.

DEM grid size	Study site	Soil Type	Experimental setting [width (m) × length (m)]	Reference
20 cm	Rix's Creek Coal Mine, Australia	mudstone spoil	Engineered slope (100 × 20)	(Hancock et al., 2008)
5 cm	St. Märgen, Germany	dystric cambisol	Virtual field plots (4 × 7)	(Schmid et al., 2004)
2 cm	Perugia, Italy	Calcaric Cambisol	field experiment plot (2 × 11, 4 × 11, and 8 × 22)	(Vinci et al., 2016)
2 cm	Andalusia, Spain	colluvium soil	field experiment plot (∼20 × 50)	(Eltner & Baumgart, 2015)[a]
1 cm	Andalusia, Spain	colluvium soil	field experiment plot (∼20 × 50)	(Eltner & Baumgart, 2015)[a]
1 cm	Perugia, Italy	Calcaric Cambisol	field experiment plot (8 × 22)	(Vinci et al., 2015)
1 cm	China	Loess, disturbed	Soil pan (5 × 1)	(Zhang et al., 2016)
1 cm	Boise Front Range, US	Andisol	Field experiment plot (2 × 4.25)	(Eitel et al., 2011)

[a] Authors divided the experimental plot into the eastern and western sections, with different grid sizes of 1 cm and 2 cm, respectively.