Geomorphology 306 (2018) 224–234

Contents lists available at ScienceDirect

Geomorphology

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

Accuracy of topographic index models at identifying ephemeral gully trajectories on agricultural fields

Aleksey Y. Sheshukov *, Lawrence Sekaluvu [1], Stacy L. Hutchinson

Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66506, USA

ARTICLE INFO

Article history:
Received 31 March 2017
Received in revised form 20 December 2017
Accepted 25 January 2018
Available online 31 January 2018

Keywords:
Ephemeral gully
Erosion
Topographic index
Conservation practice
Digital elevation model

ABSTRACT

Topographic index (TI) models have been widely used to predict trajectories and initiation points of ephemeral gullies (EGs) in agricultural landscapes. Prediction of EGs strongly relies on the selected value of critical TI threshold, and the accuracy depends on topographic features, agricultural management, and datasets of observed EGs. This study statistically evaluated the predictions by TI models in two paired watersheds in Central Kansas that had different levels of structural disturbances due to implemented conservation practices. Four TI models with sole dependency on topographic factors of slope, contributing area, and planform curvature were used in this study. The observed EGs were obtained by field reconnaissance and through the process of hydrological reconditioning of digital elevation models (DEMs). The Kernel Density Estimation analysis was used to evaluate TI distribution within a 10-m buffer of the observed EG trajectories. The EG occurrence within catchments was analyzed using kappa statistics of the error matrix approach, while the lengths of predicted EGs were compared with the observed dataset using the Nash–Sutcliffe Efficiency (NSE) statistics. The TI frequency analysis produced bi-modal distribution of topographic indexes with the pixels within the EG trajectory having a higher peak. The graphs of kappa and NSE versus critical TI threshold showed similar profile for all four TI models and both watersheds with the maximum value representing the best comparison with the observed data. The Compound Topographic Index (*CTI*) model presented the overall best accuracy with NSE of 0.55 and kappa of 0.32. The statistics for the disturbed watershed showed higher best critical TI threshold values than for the undisturbed watershed. Structural conservation practices implemented in the disturbed watershed reduced ephemeral channels in headwater catchments, thus producing less variability in catchments with EGs. The variation in critical thresholds for all TI models suggested that TI models tend to predict EG occurrence and length over a range of thresholds rather than find a single best value.

1. Introduction

Soil erosion on hillslopes of cultivated crop fields is a significant source of sediment in streams and waterbodies. Soil erosion is expressed in forms of sheet and rill erosion, ephemeral gully erosion, and classic gully erosion (Foster, 1986). Sheet and rill erosion can occur at any point of the hillslope while ephemeral and classical gullies are present mainly along waterways in a lower part of the slope where overland flow becomes concentrated. The U.S. Department of Agriculture (USDA) National Resource Inventory on soil erosion from cropland (USDA-NRI, 2015) has reported an average annual sediment load of 2.1 tons per acre in Kansas and an overall 43% decrease in soil erosion in the U.S. since 1982. This reduction has been mainly due to an adoption of conservation practices; however, the impact of ephemeral gully erosion is not fully understood. Identification of concentrated flow waterways is crucial for soil loss calculations and placement of conservation practices.

Ephemeral gullies (EGs) are small channels eroded by concentrated flow on agricultural landscapes that can be filled by tillage only to reform again in the same location due to subsequent runoff events (SSSA, 2008). If not corrected, EGs can grow in length from one runoff event to another. Channels from small rills of 10 cm wide and <1 m long to ones wider than 1 m and several hundred meters long are classified as EGs. EGs are present on cultivated crop fields whereas classical gullies are abundant on rangeland and pastureland where they are normally left untreated for prolonged periods of time (USDA-NRCS, 2007; Fox et al., 2016). Studies indicated that in the areas of significant agricultural production, contribution of EG erosion could be substantial, close to or exceed estimates of sheet and rill erosion. A review of the data collected in different parts of the world reported EG contribution to overall soil loss rates ranged from 10% to 94% (Poesen et al., 2003). Bennett et al. (2000) analyzed EGs from field studies in the U.S. and

* Corresponding author.
E-mail address: ashesh@ksu.edu (A.Y. Sheshukov).
[1] Presently at Purdue University, West Lafayette, Indiana, U.S.

https://doi.org/10.1016/j.geomorph.2018.01.026

reported contribution of about 20% in Iowa, and 40% to 60% in actively eroding areas of Alabama and Mississippi. In central Kansas, ephemeral gully erosion can reach up to 40% of total soil erosion (Douglas-Mankin et al., 2011).

Ephemeral gullies represent a transitional landscape feature that is a result of channel and hillslope flow and erosion processes. Small rills on hillslopes can develop into EGs when surface runoff has enough stream power at the initiation point of the rill to detach soil particles and sufficient sediment transport capacity to carry sediment along the channel (Nouwakpo et al., 2010; Karimov and Sheshukov, 2017). The characteristics of runoff that are crucial in the formation of EGs depend on factors related to topography, soil properties, and land management of contributing area (Poesen et al., 2002; Valentin et al., 2005; Knapen et al., 2007; Daggupati et al., 2013).

Topographic index (TI) models have been widely used to identify the places where EGs may form in agricultural fields (Moore et al., 1988; Prosser and Abernethy, 1996; Vandekerckhove et al., 1998; Poesen et al., 2003; Daggupati et al., 2013, 2014; Momm et al., 2013). TI models use a topographic threshold concept to identify EG locations. A topographic index is calculated at each point in the field as a function of site-specific characteristics, mainly derived from topographic information, such as, local slope, contributing area, curvature, and flow length (Thorne et al., 1986; Moore et al., 1988; Montgomery and Dietrich, 1992). However, other factors affecting overland flow, such as precipitation depth, surface roughness, and critical soil shear stress, were also used in previous studies (Daggupati et al., 2014; Yi et al., 2017). Locations in a field where the index exceeds a specified critical threshold belong to the gully trajectory.

Finding the value of critical threshold is important for accurate identification of locations (or initiation points) and length of EG trajectory (Montgomery and Dietrich, 1988; Desmet et al., 1999; Souchere et al., 2003; Daggupati et al., 2013; Momm et al., 2013; Buchanan et al., 2014; Torri and Poesen, 2014). These predictions are especially important when TI models are used in soil erosion and watershed modeling tools to evaluate soil erosion rates for risk assessment of non-point source pollution (Knisel, 1980; Flanagan et al., 1995; Woodward, 1999; Bingner and Theurer, 2005; Gordon et al., 2007).

The use of geographical information systems (GIS) allows a development of methods for automated calculation of topographic indexes, but the accuracy depends on the quality of input datasets, for example, resolution of a digital elevation model (DEM; Daggupati et al., 2013; Momm et al., 2013). Knowledge of specific structural and watershed features affects flow routing schemes and, as a result, topographic index calculations. Geographical location and geomorphological features were also found to affect critical threshold values (Vandekerckhove et al., 1998). Thus, a critical threshold value appropriate in one area may not satisfy a network of EGs in a different geographical area. This study investigates the accuracy of four topographic index models at predicting (1) catchments with EG initiation points and (2) length of EG trajectories in central Kansas, USA. It aims at evaluating topographic index distribution within EG trajectories and assessing the impacts of critical TI thresholds on EG identification. The results are compared for two paired watersheds with different levels of implemented structural conservation practices.

2. Study watersheds

The study was conducted in two adjacent watersheds: Dry Turkey Creek (DTCW; area of 9525 ha) and Running Turkey Creek (RTCW; 9871 ha). DTCW and RTCW are classified as 12-digit Hydrologic Unit Code (HUC; classification by Seaber et al., 1987; https://water.usgs.gov/GIS/huc.html) watersheds (110300120207; 110300120206); they are subwatersheds of the Little Ark River basin (8-digit HUC 11030012) located in McPherson County of central Kansas, USA (Fig. 1). The watersheds have similar physiographical, climate, soil, and agricultural management characteristics. The median slope of the area is 2.1%. Soils are mainly silt clay loam and silt loam, both sensitive to soil erosion (Karimov et al., 2014). The watersheds received an average of 830 mm annual precipitation from 1990 to 2010. About 40% of rainfall occurs in late spring and early summer when land is normally bare or poorly protected and summer crops are in early growth stage, which causes significant soil losses on agricultural fields due to rill and ephemeral gully erosion.

The prevailing land use in both watersheds is cropland (80.5% in DTCW and 85.8% in RTCW) followed by pastureland (10.7% and 6.9%) and forest (4.2% and 3.6%). The forested areas are mainly in riparian buffers along natural streams and served as wind breaks between parcels of cultivated land. Based on cropland dataset from the USDA National Agricultural Statistics Service (USDA-NASS, 2016) and USDA Farm Service Agency Common Land Unit layer of field boundaries (Gao et al., 2017), cultivated cropland were found in 115 and 125 quarter-sections of land (area of 65 ha) in DTCW and RTCW, respectively. The prevailing crop was winter wheat typically planted in early fall, growing through winter, and harvested in late spring. Other major crops were warm season crops of grain sorghum, soybeans, and corn. Winter wheat was typically planted annually under conventional tillage, whereas warm season crops were rotated annually (Roozeboom et al., 2009; WRAPS, 2011).

Structural agricultural conservation practices (e.g. terraces and grassed waterways) were implemented on many fields in the watersheds (Figs. 1 and 2). A terrace is an earthen embankment or a ridge built on the contour across the slope of a crop field to intercept runoff water and reduce soil erosion, while grassed waterways are constructed downhill graded channels, seeded to grass, and designed to direct concentrated runoff from adjacent terraced cropland and prevent soil erosion (Fig. 2a). The grassed waterways also help reducing gully erosion in areas of concentrated flow. DTCW had a higher number of conservation practices than RTCW. Terraces were installed in 58 quarter-sections in DTCW with a total length of 160 km, and in 21 quarter-sections in RTCW with a length of 49 km. There were 100 grassed waterways with 40 km in total length in DTCW, and 44 grassed waterways with a total length of 20 km in RTCW. DTCW had terraces installed in conjunction with grassed waterways in 42 quarter-sections as compared to only 12 in RTCW.

3. Data preparation

3.1. Processing a DEM

Predictive methods of EG identification, including topographic index models, require the use of geospatial datasets, such as, surface elevation, land use and land cover, soil, and agricultural field boundaries. The main dataset needed for surface flow processing is a DEM. For this study, the highest resolution 1/9 arc-second (3-m) DEM produced by the US Geological Survey (USGS) available at the national level was acquired from the US Department of Agriculture (USDA) Geospatial Data Gateway (USDA-NRCS, 2016). That DEM contains a much-improved base of elevation data for calculating slope, drainage information, and hydrologic derivatives (USGS, 2016). Nevertheless, land manipulation obstructions in the form of roads and dams create breakage of surface water flow that is structurally resolved by installation of culverts, underground pipes, and other underground connection flow systems, which are invisible to the DEM. To account for such hydrological connections and eliminate the flow breakage, the DEM was hydrologically reconditioned. The locations of road culverts and outlets of field ponds were achieved by field reconnaissance surveys and consultations with local stakeholders and watershed extension specialists, and then used to identify breaks in flow pathways (Fig. 2a). The areas of potential water accumulation immediately upstream of culvert locations were manually connected in the DEM with the streams initiating below the culverts by lowering the elevation of the cells or "burning-in" the streams using the AGREE method implemented within the DEM