Geomorphology 265 (2016) 98–106

Contents lists available at ScienceDirect

Geomorphology

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

A new method of tree structure for analysing nested watershed shape

Yong-Gang Chen [a,b,*], Chun-Ju Yang [a,b], Xiao-Yin Chen [a,b], Tian-Wu Ma [a,b], Li Wang [c], Jing-Yuan Du [c]

[a] School of Environmental and Resource Sciences, ZHEJIANG A&F UNIVERSITY, Lin'an 311300, China
[b] Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon Sequestration, Lin'an 311300, China
[c] School of Information Engineering, ZHEJIANG A&F UNIVERSITY, Lin'an 311300, China

ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form 25 April 2016
Accepted 26 April 2016
Available online 30 April 2016

Keywords:
Watershed
Watershed shape
Tree structure
Multi-scales
Nested watershed

ABSTRACT

A new method based on tree structure is proposed to study the relationship of multi-scale watershed shapes. Considering the nested relationship of watershed characteristics, the method uses a tree structure to reflect different watershed scales. We investigated the Loess Plateau of Shanxi Province, China, using 30-m resolution Digital Elevation Models (DEMs). The study consists of three stages: (1) by using Geographic Information System (GIS) tools, different scale watersheds were extracted from the DEMs and used to build a tree structure model based on spatial inclusion relationships; (2) the tree structure was transformed into a table based on the size of watershed area; and (3) the shape was quantified by roundness and tightness coefficients to analyse shape relationships among different scales of watersheds. The application of the method to 15 types of geomorphological features suggests that the smaller the watersheds are, the rounder they tend to be. The new tree structure method introduced here provides a good understanding of nested relationships between watershed characteristics.

1. Introduction

Watershed geomorphology is the result of mutual interaction among surface materials, rainfall and runoff for a long term, and tectonic movement (Lu, 1991). Surface water erosion is the most common and strongest geomorphic process in many cases except polar regions and areas above the snow line (Cheng and Jiang, 1986; Lu, 1991; Pelletier, 2003). A watershed is a basic geographical unit, which can be used to study geomorphological features. Quantitative research on watershed morphological characteristics plays a significant role in geomorphology (Strahler, 1957; Sutherland, 1994; Zheng, 2000; Liu et al., 2009). Major indexes of watershed geomorphology include area, plan shape, altitude, slope, asymmetry, and drainage structure.

Plan shape of a watershed is one of the most basic watershed attributes, which influences hydrological conditions including water flow and the formation of floods (Cheng and Jiang, 1986; Lu, 1991; Tuttle et al., 1996; Déborah et al., 2003; Debarry, 2004; Ivanov, 2006). Watershed shape also affects hillslope erosion (Jane and Qiong, 2008; Christian and Crosta Giovanni, 2008). Classic Hack's (1957) law implies that with the increase in the watershed area, the watershed shape will become narrower (Willemin, 2000). By applying the method of unrolling perimeter radials for Fourier series analysis, Richard (1976) analysed shape of 336 watersheds and discovered that watershed shape is influenced by geographical environment, watershed grades and tributary quantity.

Shape parameters such as the roundness coefficient, and long-narrow degree objectively reflect different shapes of watersheds (Horton, 1932; Strahler, 1952; Potter, 1953; Schumm, 1956). Cheng and Jiang (1986) made a systematic experiment on how to express topography of watersheds on a loess hill in Northern Shanxi Province, China. Using the circularity ratio and elongation ratio, they found the effects of both lithology and the total slope of the area.

Although the studies on watershed shape have been developing, previous studies seldom use the hierarchical feature of the tree structure. The feature can express nested relationships among different scales of watersheds. By using tree structure and considering nested relationships, this paper puts forward an analytical method to study watershed shape relationships at different scales.

2. Study area

The study area is a typical zone of severe soil erosion on the Loess Plateau, China (Fig. 1). The Loess Plateau is characterized by extensive and thick loess deposits. Their thickness generally ranges from 100 to 200 m with a maximum of 300 m. It evolved during the Quaternary (Zhang, 2005; Li, 2006). The study area is featured by "loess geomorphology" because of massive loess covered, while few rocky hills, flats and basins located in the middle. The northern area is adjacent to the transitional wind sand-loess geomorphology (Li, 2006; Zhou, 2011). Loess tablelands, ridges, hills and karst topography are present in the study area and show different spatial distribution. The area has been suffering severe soil erosion which is a source of the Yellow River sediment (Gan, 1989). Because the area can well reflect the relationship of

* Corresponding author at: School of Environmental and Resource Sciences, ZHEJIANG A&F UNIVERSITY, Lin'an 311300, China.
E-mail address: cyg_gis@163.com (Y.-G. Chen).

http://dx.doi.org/10.1016/j.geomorph.2016.04.023
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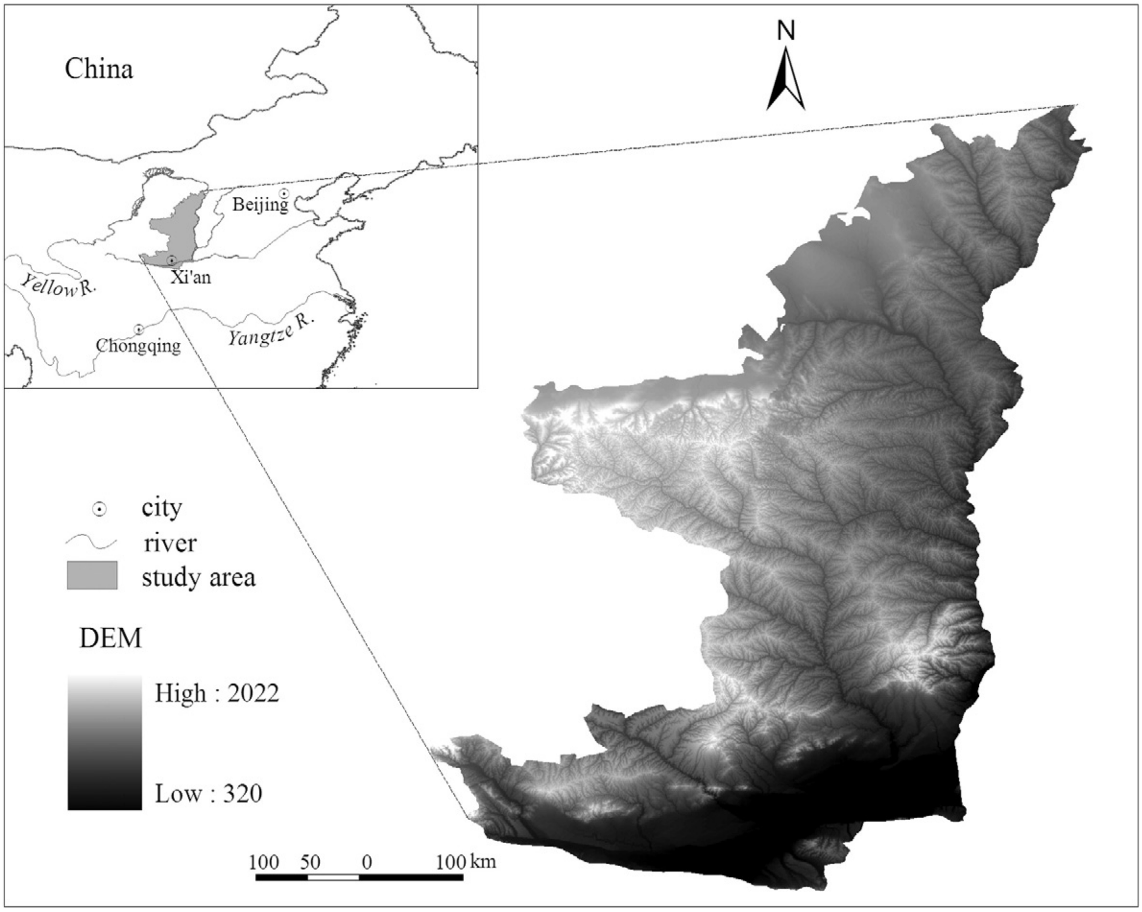

Fig. 1. DEM and location of the study area.

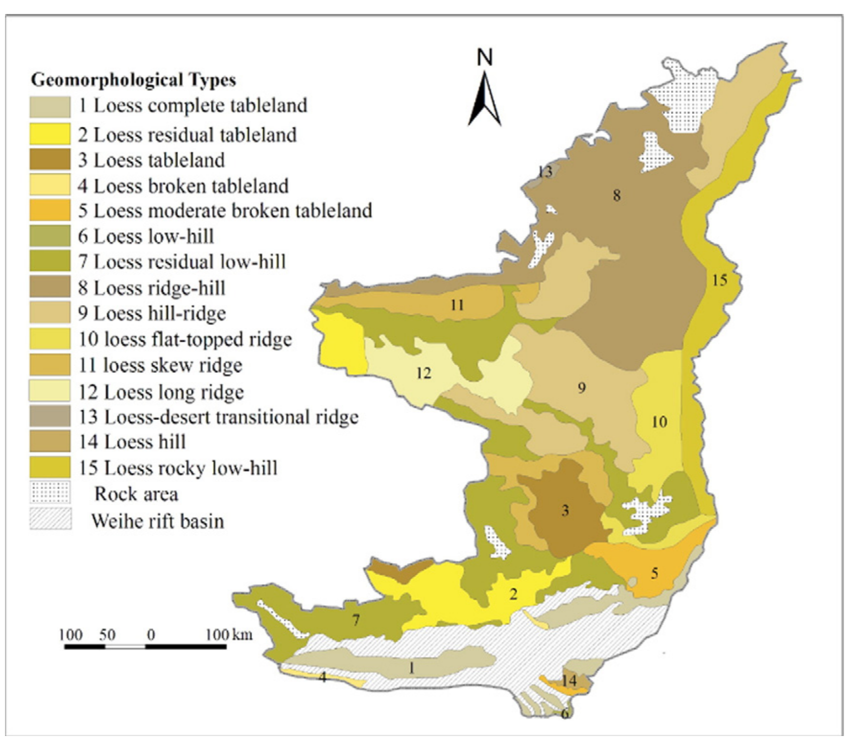

Fig. 2. Distribution of geomorphological types in the study area (Board, 2009).