Geomorphology 239 (2015) 41–47

Contents lists available at ScienceDirect

Geomorphology

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

Improved classification of drainage networks using junction angles and secondary tributary lengths

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ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form 2 March 2015
Accepted 3 March 2015
Available online 10 March 2015

Keywords:
Drainage network geometry
Confluence junction angle
Secondary tributary lengths
River network classification

ABSTRACT

River networks in different regions have distinct characteristics generated by geological processes. These differences enable classification of drainage networks using several measures with many features of the networks. In this study, we propose a new approach that only uses the junction angles with secondary tributary lengths to directly classify different network types. This methodology is based on observations on 50 predefined channel networks. The cumulative distributions of secondary tributary lengths for different ranges of junction angles are used to obtain the descriptive values that are defined using a power-law representation. The averages of the values for the known networks are used to represent the classes, and any unclassified network can be classified based on the similarity of the representative values to those of the known classes. The methodology is applied to 10 networks in the United Arab Emirates and Oman and five networks in the USA, and the results are validated using the classification obtained with other methods.

1. Introduction and literature review

Drainage networks can appear remarkably distinct in different regions depending on climatic, physiographic, and topographic constraints that influence the development of river networks. This difference allows us to classify and investigate different channel networks, thereby defining homogenous neighborhoods. To differentiate between river networks, several authors have sought to identify classes of drainage networks such as dendritic, parallel, pinnate, rectangular, and trellis (Zernitz, 1932; Parvis, 1950; Howard, 1967; Abrahams and Flint, 1983). Zernitz (1932) and Howard (1967) observed that dendritic networks typically tend to be tree-like by freely developing with tributaries that merge at moderately acute angles. Parallel networks appear as a parallel form by developing on large surface slopes, and they are characterized by straight main channels and tributaries that merge at acute junction angles (Zernitz, 1932; Howard, 1967; Mosley, 1972; Phillips and Schumm, 1987; Jung et al., 2011). Pinnate networks tend to be feather-like and formed by straight major channels and many small tributaries that merge at very acute junction angles (Zernitz, 1932; Howard, 1967). Zernitz (1932) and Howard (1967) also identified that rectangular networks have stream course irregularities with a large number of right angle bends and tributaries joining at right angles. Trellis networks have small and short channels that merge at nearly right angles by forming lattice-like channels (Parvis, 1950; Howard, 1967; Abrahams and Flint, 1983). Fig. 1 shows examples of the network types described above.

These differences have led to development of classification systems for the identification of drainage networks based on quantitative measures. For the river network classification, Morisawa (1963) studied directions of first-order streams indicating headwater channels without any tributaries. Argialas et al. (1988) proposed a classification system based on third-order networks digitized from aerial photos of various network types. Ichoku and Chorowicz (1994) improved a quantitative methodology using digital elevation models (DEMs) with 14 features of river networks. In a more recent study, Mejia and Niemann (2008) presented another classification system on the basis of three measures, namely the drainage area increment, the channel course irregularity, and the tributary junction angle, derived from scaling-invariance concepts to classify and characterize different channel networks. We propose a new methodology to directly discriminate between five river networks by only considering the tributary junction angles with the secondary tributary lengths. The river network classification process is simpler than other approaches and also no other existing method provides quantitative values to characterize the networks. The values derived from the method in this study can also be utilized in the regional frequency analysis as new physiographical characteristics.

Regional frequency analysis is commonly used in the area of hydrology and water resources to transfer information from gauged stations to ungauged stations where little or no data are available (Ouarda et al., 2001; Chokmani and Ouarda, 2004). The regional frequency analysis procedure can be improved when adequate estimation of the

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http://dx.doi.org/10.1016/j.geomorph.2015.03.004
0169-555X/

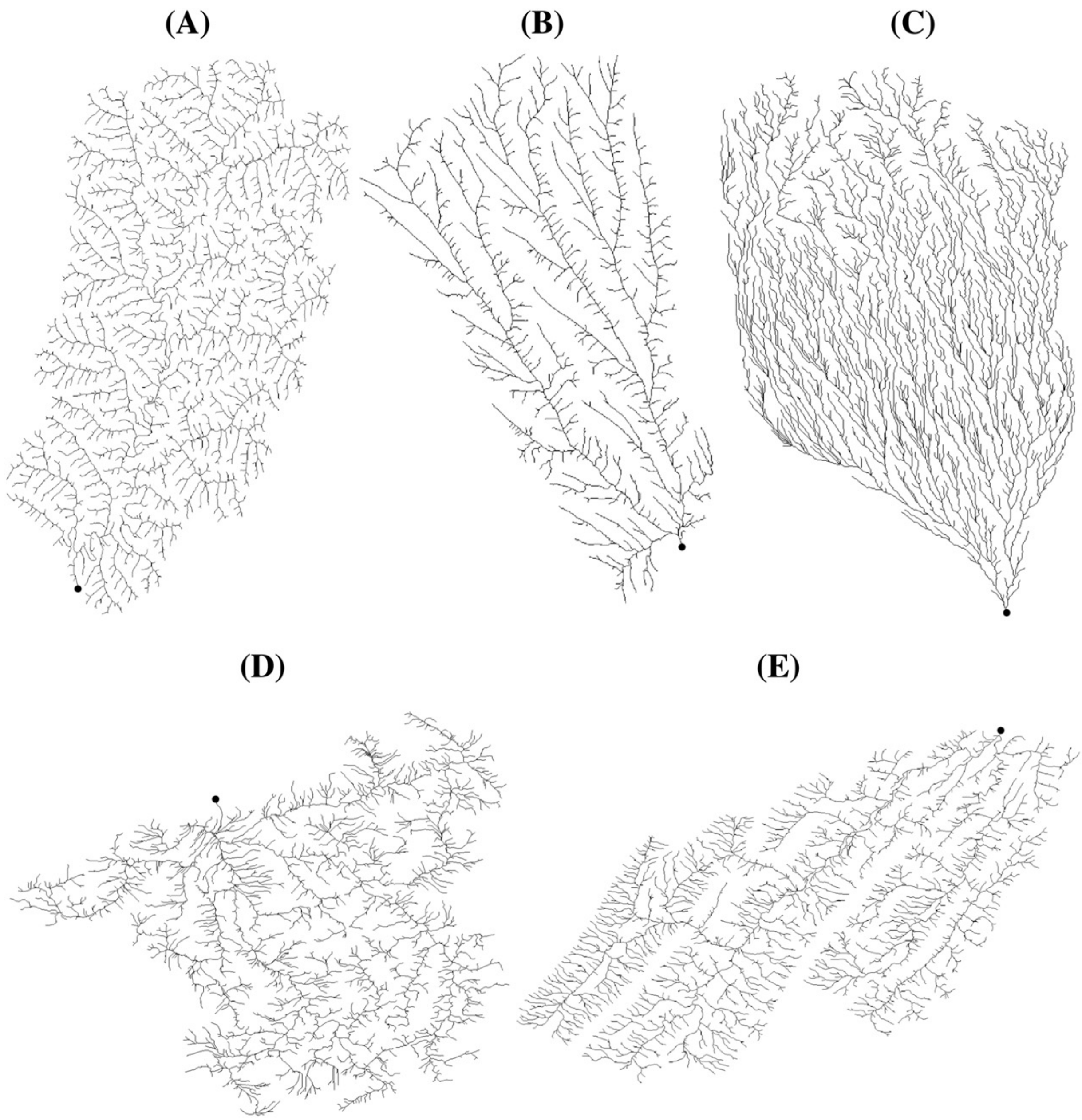

Fig. 1. Examples of the five network types in the USA: (A) Buffalo Creek, WV, for dendritic network; (B) Duck Creek, CO, for parallel network; (C) Star Wash, AZ, for pinnate network; (D) Salmon River, NY, for rectangular network; and (E) Peters Run, WV, for trellis network. The black dot indicates the outlet of each network and the line means channels in a basin.

physiographical characteristics of the gauged stations is obtained in the analysis (Shu and Ouarda, 2007; Ouarda and Shu, 2009). The group of stations is commonly called the *neighborhoods*, and homogenous neighborhoods are required to conduct the regional frequency analysis because geographical proximity is not a guarantee of hydrological similarity (Reed et al., 1999; Ouarda et al., 2001). These homogenous neighborhoods can be clearly determined when river networks and their properties are carefully analyzed. When accurate information about physiographical features is used to make the homogeneous regions for the regional frequency analysis, the efficiency of the analysis may be improved. It is because identification of the homogenous areas helps us to obtain locations where a similar hydrological behavior is shown and because the variations in flow properties have correlations with the variation in regional physiographic characteristics (Pandey and Nguyen, 1999; Chokmani and Ouarda, 2004).

The rest of the paper is organized as follows. In Section 2, the data sets used in this work are described; Section 3 presents the proposed classification methodology; and the results of the study are outlined in Section 4. Finally, conclusions are summarized in Section 5.

2. Data set

Fifty river networks in the USA that are grouped into the five types of drainage networks identified in previous studies are selected for this study as shown in Table 1 (Mejia and Niemann, 2008; Jung et al., 2011; Jung and Ouarda, 2014). These include networks in arid, semiarid, and nonarid regions. The drainage networks of the watersheds were defined by estimating flow directions and contributing areas with the summation of the total areas based on the DEMs (O'Callaghan and Mark, 1984; Tarboton et al., 1991; Mejia and Niemann, 2008; Jung et al., 2011). The DEMs of the river networks investigated in this work are obtained through the Seamless Data Distribution System (SDDS) from the U. S. Geological Survey (USGS). The horizontal resolution for the DEMs is 1 arc-second, which generates ~30-m grid cells with a