Geomorphology 204 (2014) 42–48

Contents lists available at ScienceDirect

Geomorphology

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

# Discrimination of tower-, cockpit-, and non-karst landforms in Guilin, Southern China, based on morphometric characteristics

Fuyuan Liang [a,*], Bo Xu [b]

[a] Department of Geography, Western Illinois University, Macomb, IL 61455, USA
[b] Department of Geography and Environmental Studies, California State University, San Bernardino, San Bernardino, CA 92407, USA

ARTICLE INFO

*Article history:*
Received 24 January 2013
Received in revised form 14 July 2013
Accepted 23 July 2013
Available online 31 July 2013

*Keywords:*
Landform classification
Morphometric analysis
Karst landforms
DEMs

ABSTRACT

Depressions are well developed in certain types of karst landform assemblages. These natural depressions should not be simply filled and removed during the preparation of DEMs. This study presents a research to distinguish karst landform assemblages which tend to have natural depressions from other karst landform assemblages and non-karst landforms in the Guilin area of China, by examining their morphometric characteristics derived from a 30-m resolution DEM. The variations in the morphometric characteristics are examined at neighborhood level instead of pixel level. The DEM is divided into square tiles with a specific spatial scale. Statistical indicators of typical morphometric characteristics such as the area ratio, elevation, slope, and curvature are calculated for each tile. Discriminant analysis (DA) is then performed to discriminate tower karst, cockpit karst, and non-karst landforms. These procedures are repeated at the scales of 0.45, 0.9, 1.8, 2.7, 3.6, and 4.6 km. Comparison of the mapping results with a reference geomorphic map shows that the DA works best for the 2.7 km tiles with an overall accuracy of 80.06%. The resulting map can be used to guide whether depressions should be retained or removed during DEM preparation. This method, with appropriate modifications and improvements, can also be used to map the karst landforms of the whole of southern China. With such a comprehensive map, geomorphologists would be able to examine the development of karst landform assemblages at a broader view to unveil their genesis and evolution processes.



## 1. Introduction

Topographic depressions are very common in digital elevation models (DEMs) and some of them are artifact features resulting from errors in DEMs (Mark, 1988; Lindsay and Creed, 2005, 2006). Depressions are usually filled before DEMs are used in hydrological modeling (Burrough and McDonnell, 1998; Wilson and Gallant, 2000). However, removal of all depressions is often unacceptable because some depressions are true phenomena, particularly in karst and glaciated terrains. Natural depressions such as sinkholes or dolines are well developed in karst areas and considered as the index landform of karstification (Ford and Williams, 2007). Such natural depressions should be retained in DEMs. Maps may be useful to show the distribution of karst landforms including true depressions. Currently available geomorphological maps usually categorize all karst areas into a single landform type mainly based on lithology (Veni, 2002; Ford and Williams, 2007; Zhu et al., 2013). However, natural depressions are not equally developed in all karst areas. They tend to develop in certain types of karst landform assemblages where the morphological characteristics favor the development of active foci of dissolution (Williams, 1972; Day and Huang, 2009). Therefore, maps of different types of karst landform assemblages in relation to actual depressions will be of great value.

This study creates a map showing two different types of karst landform assemblages in Guilin, China. The surface karst landforms in Guilin are characterized by residual hills with steep slopes (Tang and Day, 2000). Geomorphologists have distinguished two types of karst landform assemblages in this area: tower karst and cockpit karst (Zeng, 1982; Yuan, 1984; Zhu et al., 2013). Tower karst (fenglin-plain or peak forest) is characterized by isolated hills rising from an alluvium plain (Fig. 1A). By contrast, cockpit karst (fengcong-depression or peak cluster) consists of clustered peaks that share a common base with deep depressions (Fig. 1B — Zhu, 1982; Yuan, 1984; Sweeting, 1995; Tang and Day, 2000; Waltham, 2008). Other landforms on insoluble rocks in Guilin (Fig. 1C) are considered as non-karst landforms in this study. Obviously, most depressions in tower karst and non-karst areas should be removed during DEM processing; whereas, depressions in the cockpit karst areas should be retained as they tend to be actual phenomena, though some of them might result from DEM errors.

A geomorphological map of these two types of karst landforms will help geomorphologists better understand the controls and evolution of the landforms (Yuan, 1984; Zhu, 1988; Waltham, 2008; Day and Huang, 2009; Zhu et al., 2013). The two types of landforms are also well developed in southern China other than the Guilin area, although their morphometric characteristics may be slightly different

* Corresponding author. Tel.: +1 3092982956; fax: +1 3092983003.
*E-mail address:* F-Liang@wiu.edu (F. Liang).

0169-555X/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.geomorph.2013.07.026


**Fig. 1.** Google Earth screenshots of satellite images draped on a DEM showing typical (A) tower karst, (B) cockpit karst, and (C) non-karst landforms in the study area. Scales are approximate.

(Yuan, 1992; Sweeting, 1995; Zhu et al., 2013). Current knowledge about the distribution of karst landforms in southern China mainly came from field observations in limited areas (Yuan, 1984; Gao et al., 1986; Lu, 1986; Zhu, 1988). To our knowledge, a comprehensive karst map has not been available for southern China. This GIS-based pilot study will enable the automated mapping of tower and cockpit karst over southern China, which is essential for discussing factors affecting landform development at a broader scale.

## 2. Study area

The study area (~4170 km$^2$) is located in the south of Guilin region, China (Fig. 2), which is well-known for its spectacular karst landforms mainly developed on the Devonian and Carboniferous limestone (Deng et al., 1988). The karst landforms exist within the Guilin basin, a composite N–S trending synclinal basin surrounded by the Haiyang Mountain in the northeast and Jiaqiao Ling (Mountain) in the southwest. Both mountains are developed on insoluble rocks and thus are considered as non-karst landforms. Tower karst mainly occurs in the central part of the syncline, while cockpit karst exists on the flanks of the syncline or at the periphery of the basin. The Lijiang River cuts through the big chunk of cockpit karst at the center of the basin. Both sides of the Lijiang River from Guilin to Yangshuo are known as one of the most beautiful and spectacular karst landform assemblages in the world (Sweeting, 1995).

## 3. Methodology and data

Depending on the scale and purpose of mapping, landform entities can be categorized into four levels: landform elements, landform types, physiographic systems, and physiographic regions (MacMillan et al., 2004). Delineation of tower, cockpit, and non-karst landforms can be regarded as a landform classification at the level of physiographic systems. GIS-based geomorphometric analysis has been widely used to classify landforms at various special scales (Guzzetti and Reichenbach, 1994; MacMillan et al., 2004; Iwahashi and Pike, 2007). However, these methods cannot be simply adapted to produce a geomorphological map of tower and cockpit karst landforms.

Both specific and general morphometric analyses (Evans, 1972) have been used to examine karst landforms since the 1970s. Most of such studies compared the morphometric characteristics of individual karst landforms such as closed depressions and residual hills (Williams,

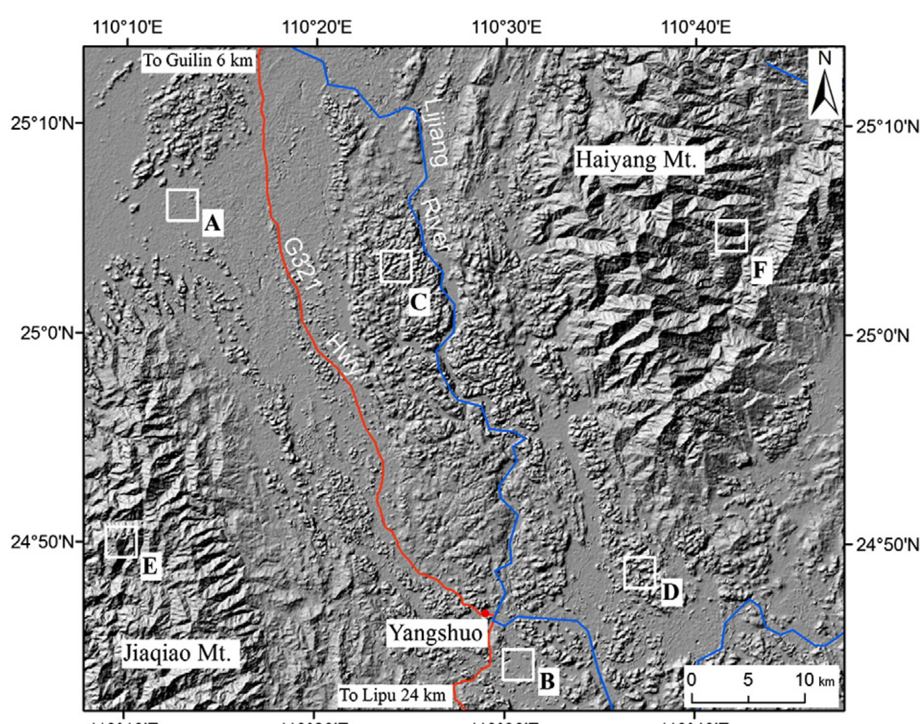


**Fig. 2.** Hillshaded DEM showing the terrain of the study area. Six squares (A to F) show the locations of six exemplary tiles representing different types of landform assemblages (Table 1).