DEM and GIS based morphometric and topographic-profile analyses of Danxia landforms

Wen Zhang
Department of Natural Environmental Studies
The University of Tokyo
Kashiwa, Japan
zhangwen@csis.u-tokyo.ac.jp

Takashi Oguchi
Center for Spatial Information Science
The University of Tokyo
Kashiwa, Japan
oguchi@csis.u-tokyo.ac.jp

Yuichi S. Hayakawa
Center for Spatial Information Science
The University of Tokyo
Kashiwa, Japan
hayakawa@csis.u-tokyo.ac.jp

Abstract—**"Danxia landform" is a landform type originally defined in China, characterized by red-colored sandstones and steep cliffs, and developed through long-term erosion. In recent years, Danxia landforms have been receiving international attention, and six examples in China became a UNESCO World Natural Heritage in 2010. However, morphometric studies of Danxia landforms in China have been very limited. We conducted DEM-based geomorphometric analyses for 45 watersheds and 319 second-order sub-watersheds of Mt. Danxia, a typical Danxia landform in China. Investigated properties include drainage basin area, basin relief, relief ratio, slope, and hypsometry. Mountains and hilly lands dissected by fluvial processes including Danxia landforms can also be characterized by stream longitudinal profiles and valley transverse profiles. Therefore, both profiles for the watersheds in Mt. Danxia were extracted from a DEM and the former was used to analyze the stream length gradient index (*SL* index), the stream concavity index, and the slope–area relationship. A series of morphometric analyses were conducted to infer lithologic and tectonic influences on the landforms. The results indicate that localized erosion has enhanced deepening of existing fractures rather than lateral erosion to form deep and narrow valleys, while long-term erosion provided large and gentle watersheds. Anomalously higher *SL* values often occur with knickpoints where bedrock incision is affected by lithology and faults. The results indicate that studied watersheds exhibits high spatial variations in the morphometric properties and some of them resulted from lithologic control.**

I. Introduction

Chinese scholars have defined "Danxia landform" as a landform type made up of non-marine red clastic rock with nearly horizontal strata, characterized by red rock walls or cliffs and relatively flat tops. The size of flat tops varies significantly and it is negligible where erosion provided pillars. "Danxia landform" was named after Mt. Danxia in Guangdong Province, China. Since 2010 "Danxia landform" has been listed as a UNESCO World Natural Heritage for its unique geomorphic landscapes. The heritage includes six sites in the sub-tropical zone of south-western China: Lang Mountain in Hunan Province, Mt. Danxia in Guangdong Province, Taining in Fujian Province, Mt. Longhu in Jiangxi Province, Chishui in Guizhou Province, and Mt. Jianglang in Zhejiang Province.

Research on Danxia landforms so far has focused on the definition, classification, qualitative description and discussion about the cause of the landscape [4], [6]. However, quantitative analyses on Danxia landforms have been very limited, despite recent development in geomorphometry using DEMs and GIS. In this study, we used DEMs and their derivatives as well as geology and structural data to perform a quantitative geomorphological study on Danxia landforms. This approach may provide a way to evaluate the effects of lithology and tectonics on landform development. We selected Mt. Danxia as our study area because it contains the most typical Danxia landforms.

Many previous studies on erosional landforms analyzed morphometric characteristic of watersheds and properties of river longitudinal profiles [1], [2]. This kind of approach seems to be effective for research on Danxia landforms whose development has been affected by fluvial processes. In this work, river longitudinal profiles and valley transverse profiles are extracted from a digital elevation model (DEM), and a series of morphometric analyses are conducted to understand topographic structure of watersheds in Mt. Danxia and possible controlling factors. Various parameters of drainage basin morphometry, river longitudinal profiles and valley transverse profiles were obtained from the ASTER GDEM using ArcGIS and Matlab programs.

II. Study area and regional geology

Mt. Danxia is located in the northeast of Shaoguan City of Guangdong Province, China (24°51'48''–25°04'12''N, 113°36'25''–113°47'53''E). It is situated on the southern side of the Nanling Mountains, with an area of ca. 280 km^2 and its altitude ranges from 26 to 570 m (Fig. 1). The prominent landform types in Mt. Danxia include more than 600 stony peaks, fortresses, walls, pillars (hoodoos) and natural bridges of various sizes and heights. Peng [6] suggested that five plantation surfaces of different levels formed in Mt. Danxia during the intermittent uplift of the red strata. The geomorphology of the area has also been affected by erosion due to fluvial processes and mass movements. The area has the two major structural components: 1) The NNE-trending faults of the Danxia Basin as the main faulting structure; and 2) numerous vertical joints in the red beds formed during the crustal movement in E–W and NE–SW directions [7]. The Jinjiang River and its tributaries have been acting as the chief sculptor of Mt. Danxia.

The two principal sedimentary formations in the study area are the lower Changba Formation and the upper Danxia Formation [3] (Fig. 1). Red terrestrial sedimentary rocks of the Danxia Formation correspond to areas of typical Danxia landforms.

III. Data

The main sources of data for this study are a 1:50,000 topographic map, a 1:50,000 geologic map (Fig. 1), and the ASTER GDEM. The topographic map was published by the Sun Yat-Sen University, China, in 2008. The geologic map was published by the Guandong Institute of Geological Survey, China, in 2000. The ASTER GDEM was provided by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). We downloaded the DEM for the study area from the NASA web site and rectified it into the UTM projection to ensure uniform cell size.

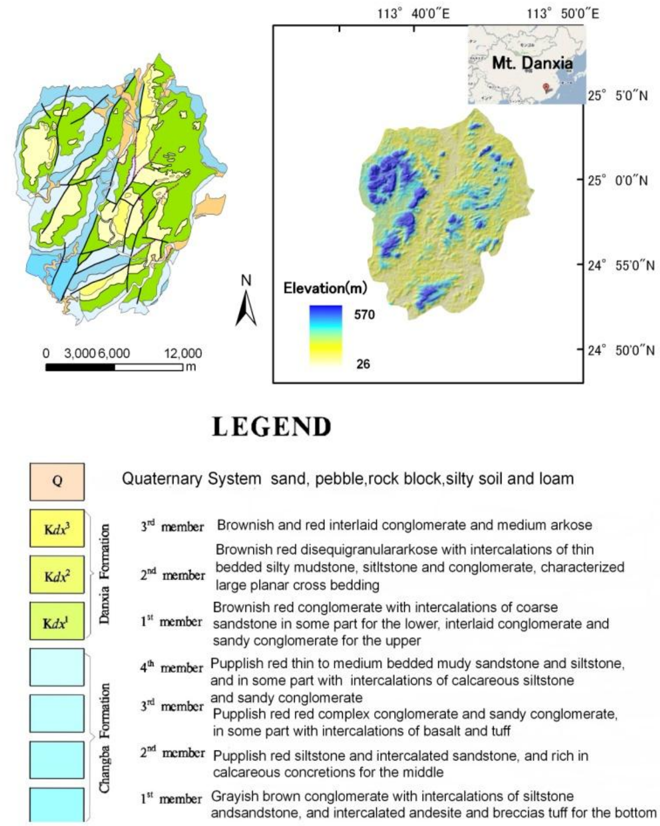

Figure 1. A digital elevation model and Geological map of Mt. Danxia

IV. Methods

To extract stream-nets and watersheds, Arc Hydro (an extension of ArcGIS, ESRI) was used. The results were overlaid on the geological map. Then we conducted a series of morphometric analyses based on: 1) DEM data for each watershed, 2) drainage networks, 3) stream longitudinal profiles, 4) stream length-gradient index (*SL* index), and 5) transverse profiles.

Stream-nets, watersheds and sub-watersheds in the study area (Figs. 2 and. 3) were delineated using the DEM. The threshold contributing area for determining channel heads varies with local climate, soil, geology, vegetation, and landscape [5]. The relationship between the drainage density and basin area was used to determine the threshold, i.e., the area at which a rapid decrease in drainage density with an increasing basin area tends to occur. Then the watersheds and sub-watersheds were delineated based on stream orders. Basic properties of sub-watersheds such as area, mean slope, and the hypsometric integral were also obtained. The longitudinal profiles of 45 streams were extracted using the stream-nets and the DEM.

The *SL* index allows the quantification of differences in erosion pattern between valleys. Hack (1973) defined the *SL* index as:

$$SL = (\Delta H / \Delta L) L \quad (1)$$

Where ΔH is the difference in elevation between the ends of the reach of interest, ΔL is the length of the reach, and L is the horizontal length from the watershed divide to the midpoint of the reach. *SL* along the rivers in the study area was calculated (Fig. 4), and its average value for each watershed was computed.

A series of transverse profiles of a watershed were extracted from the DEM. Each profile is perpendicular to the orientation of the smoothed master stream, and the sampling interval was set to be 30 m. The characteristics of each profile were investigated using basic statistical moments including mean, standard deviation (SD), skewness and kurtosis of height and slope.

V. RESULTS

A. Stream-nets and watersheds

The comparisons of delineated stream-nets and watersheds as well as the values of general morphometric properties with the geologic map revealed that the Changba and Danxia formations often corresponds to differing morphometric properties. For example, higher values of the hypsometric integral are associated with the Danxia formation rather than the Changba formation.

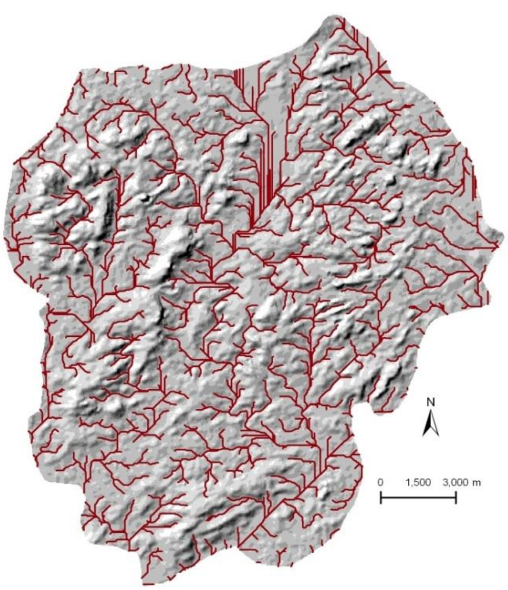

Figure 2. Extracted stream-nets

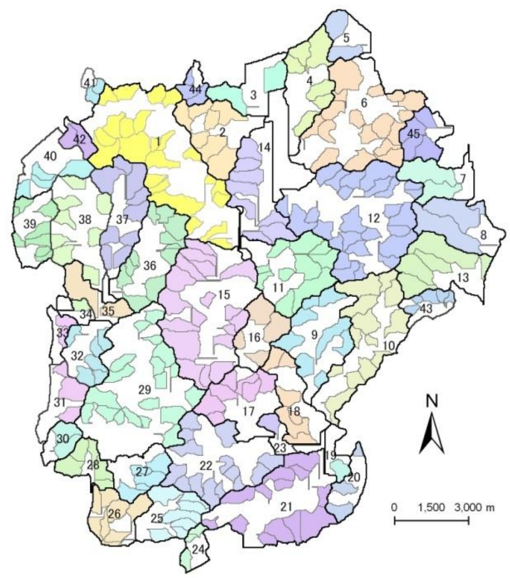

Figure 3. Distribution of sub-watersheds

B. Longitudinal profiles of streams

If a stream flows over only one lithology, its longitudinal profile tends to have a conventional concave shape, although the profile may be partly segmented or fluctuated. If the stream flows over two or more rock types, there is often a slope break at the contact, especially where the adjoining rocks have varying resistance to erosion. Anomalies in longitudinal profile frequently correspond with changes in the form of transverse profiles of valleys.

C. Stream length-gradient index (SL index)

The *SL* values range from 0.6 to 1348 m, with a mean of 66.7 m and a standard deviation is 78.6 m. Most of the study area (80%) shows *SL* smaller than 100 m. *SL* significantly changes at the boundary of the Changba and Danxia formations. High *SL* values can also result from discharge growth caused by the confluence of a large tributary. Some rivers at the center of the study area demonstrate anomalously high *SL* values, corresponding to the NNE-trending fault zone.

D. Transverse profile

The transverse profiles often show complex shapes (Fig. 5). Averaged shape parameters showing simple dimensions of a valley (width, relief and mean height) show positive correlations, reflecting relatively similar valley shape. However, stronger positive correlations occur between such parameters and skewness or kurtosis of height distribution, indicating that valley shape changes systematically with valley size. Skewness and kurtosis of slope are also positively correlated with mean and *SD* of slope, indicating that river downcutting has led to deep and steep valleys with relatively limited lateral erosion.

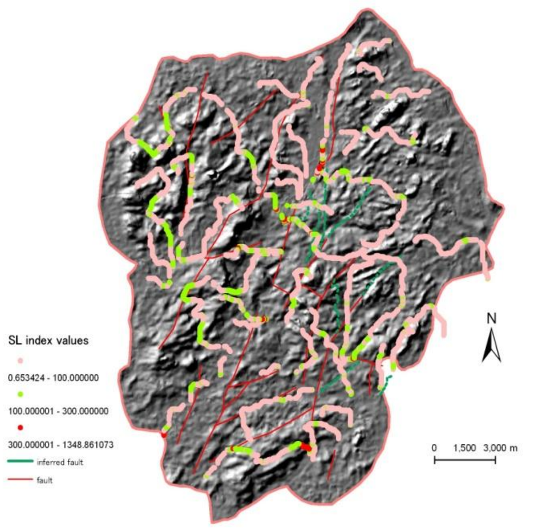

Figure 4. *SL* index along the drainage network

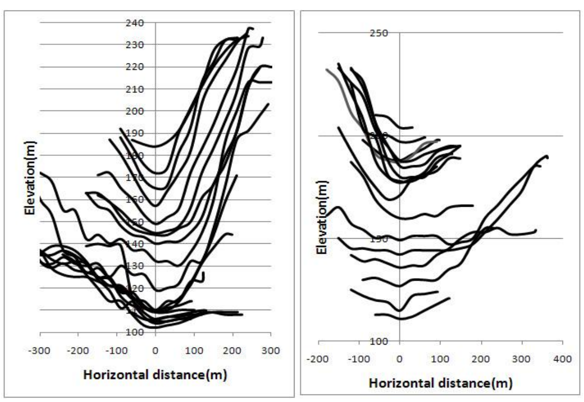

Figure 5. Examples of transverse profiles

VI. Discussion

The various morphometric analyses using the DEM helped to understand the characteristics of Danxia landforms quantitatively and objectively. It was found that watersheds in Mt. Danxia have relatively smooth and concave longitudinal profiles. This observation indicates that, in spite of complex landscape characterized by steep rock walls and pillars as shown by the valley transverse profiles, the main river of each watershed provided less complex landforms along its course. Wide valleys with gentler transverse profiles tend to have smooth and more concave longitudinal profiles, lower *SL* indices and lower gradients, suggesting that long-term erosion has created large and gentle watersheds. At the same time, local development of deep and narrow valleys is also evident.

Geologic structure such as lithologic boundaries and faults also affects both the local shape of longitudinal profiles and the *SL* index. Lithologic discontinuities created a series of anomalously high *SL* index values. General watershed properties such as the hypsometric integral also correspond to rock types to some extent. Therefore, geomorphometry of Danxia landforms and similar features requires the evaluation of multiple geomorphological properties and data for geologic structure.

Acknowledgements

We thank Prof. Peng Hua and Ms. Fang Ren for their help with data collection.

References

[1] Carretier, S., Nivière, B.,Giamboni, M.,Winter, T., 2006. "Do river profiles record along-stream variations of low uplift rate". J. Geophys. Res., 111: F02024, doi:10.1029/2005JF000419.

[2] Hack, J.T., 1973. "Stream - profile analysis and stream - gradient index". Geological Survey Journal of Research, 1(4): 421-429.

[3] Huang J., Chen Z.J., 2003. "The discussion on the definition and classification to Danxia landform". Economic Geography, 23(Suppl.): 6-11.

[4] Huang, J., 1992. "Research report on Danxia Landform in China". Tropical Geomorphology, (Suppl.): 1-36, (in Chinese).

[5] Martz, L.W., Garbrecht, J., 1992. "Numerical definition of drainage network and subcatchment areas from digital elevation models". Computers & Geosciences, 18(6): 747-761.

[6] Peng, H., 2001. "Danxia geomorphology of China: a review". Chinese Science Bulletin, 46 (Suppl. 1): 38-44.

[7] Peng, H., 2000. "Danxia Geomorphology of China and its Progress in Research Work". Sun Yat-Sen University Press (in Chinese).