A SYSTEMATIC CLASSIFICATION RESEARCH OF TOPOGRAPHIC DESCRIPTIVE ATTRIBUTE IN DIGITAL TERRAIN ANALYSIS

DONG Youfu[a, b], TANG Guoan[a, *], ZHANG Ting[a]

[a]Key laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing, Jiangsu, P.R.C., 210046;
[b]College Of Civil Engineering, Nanjing University of Technology, No.200, Zhongshan North Road, Nanjing, Jiangsu, P.R.C., 210009

KEY WORDS: DEM, Classification, Terrain Attributes, Digital Terrain Analysis, Geomorphology, Hydrology

ABSTRACT:

Topographic attributes (TAs) play an important role in quantitatively describing the characteristics of landform and its structure. At present, TAs are classified from different views by many scientists being from various fields. However, there are still some urgent problems that need to be clarified about TAs. The relationships and differences of various TAs are not revealed and a mature, widely accepted and systematic classification has not been established. Based on previous research, TAs are systematically classified in this paper, taking consideration of systematic, hierarchical and practical principles. Firstly, TAs can be divided into global TAs and local TAs in the light of their descriptive spatial extent. Secondly, according to their algorithms, TAs are classified into basic TAs, compound TAs, features TAs and statistical TAs. Thirdly, TAs are distinguished into morphologic TAs and structural TAs according to their descriptive themes. Fourthly, on the basis of the relationship of TAs values and coordinate axes direction, TAs are grouped into geometrical TAs, isotropic TAs, axial TAs, and anisotropic TAs. Moreover, TAs can be labelled as first-order TAs, second-order TAs and multiple-order TAs by partial derivatives degree of elevation data. Being parameters of landform characteristics, TAs are the basis of quantitative geomorphologic research and essential indices that differentiate landform areas. So the classification is helpful in understanding the exact semantic meaning of TAs and their interrelationships for users. And it's helpful in selecting effectively and reasonably TAs in practice. Besides, it's helpful in solving some correlative problems in the research of digital terrain analysis.

1. INTRODUCTION

Topographic attributes (TAs) have been used to quantitatively describe characteristic of landform and its structure. Their algorithms and extracting methods are the emphasis of geomorphologic research at all times. There are tens of various TAs with well extraction algorithms and procedures. Meanwhile, TAs are classified by many scientists in different fields. Wood (1996) distinguished TAs as general TAs and hydrological TAs according to their applications. TAs were classified into single TAs and composite TAs by the relationship of landform features (Wilson et al., 2000; Wu, 2001). Local TAs were differentiated from non-local TAs in light of their algorithms (Florinsky, 1998). Shary (2002) brought forward several classification rules of TAs that depended on some geophysical vector fields, coordinate axes directions, and scales. TAs were grouped into global TAs and local TAs by spatial extent, into first-order TAs, second-order TAs and multiple-order TAs by partial derivatives degree of elevation data, into slope state TAs, slope shape TAs, slope position TAs and slope complexity TAs by slope morphologic characteristics (Tang 2005). Zhou and Liu (2006) grouped TAs into landform surface parameters, morphologic features, statistics attributes and compound attributes. The relationships and differences were reflected from different views with above mentioned classification methods.

Up-to-date, there are still several urgent problems that need to be clarified about TAs. First of all, universal principles of TAs classification are absent. Various TAs have been put forward, but a mature, widely accepted and systematic classification is not established. Secondly, obscure descriptions of TA's semantic meaning are due to inclusive and duplicate relationship of TAs. Thirdly, landform description analysis largely depends on data scales and analysis scales, but most suitable analysis scales and application conditions have not been made clear so that analysis errors take place frequently. Finally, the calculation and extraction of TAs based on DEMs are deeply influenced by data organizing method and sampling characteristics.

Based on all above, ambiguous classification of TAs limits further development of digital terrain analysis. TAs' classification study is essential for digital terrain analysis and the objective of this paper is to investigate this topic. On the basis of previous researches, TAs are systematically classified according to their descriptive spatial scale, calculation method and geographical meaning, taking consideration of systematic, hierarchical and practical principles.

2. CLASSIFICATION PRINCIPLES

The classification of TAs in this paper conforms to the following principles.

TAs are basic parameters describing the characteristics of terrain form and structure. So, it is applied in TAs classification

* tangguoan@njnu.edu.cn; phone +86-13776623891; fax +86-25-85898270

that the basic theory of geomorphology and descriptive rule of geographical elements' form and structure.

In order to classify all the most TAs systematically, it should be adequately considered that the diversified relations such as their inclusions, links, levels etc. of TAs' semantic meanings and calculation methods.

TAs' hierarchies are paid much attention during the classification. As we know, landform characteristics are described at different levels from local scale to global one, from single terrain to complex one, from general description to in-depth one.

It helps to understand the semantic meanings and inherent relationships of TAs for users. So, the users can select proper TAs according to application requirement. As a result, it helps to solve the problems in the researches on geomorphology, hydrology and so on.

3. CLASSIFICATION RESULTS

3.1 The classification of TAs based on their descriptive spatial scales

TAs can be divided into global TAs and local TAs in the light of spatial scale (Table.1). A local TA describes the terrain information of a given differential point and its value is influenced by a few adjacent points. At any given point, local TAs are calculated using a fixed-size window that surrounds the point. For grid DEMs, the neighbours window is N by M grid cells. In contrast with local TAs, global TAs describe the terrain information of a region and a searching window is used during their calculation. In other words, the size of the searching window is not specified in advance, but is determined by specific terrain features during calculations. The analysis window may be rectangle, circle and ring.

Moreover, global TAs are distinguished as slope area TAs, drainage area TAs and region area TAs by their descriptive spatial extent. As we know, slope is the basic unit of landform features. A plain, valley, or hill is made up of slope. Also, the change of landform roots in the change of slope. The common parameters used to describe slope include slope steepness, slope aspect, slope length, slope extension direction, project shape and slope area. The spatial characteristics of the slope can be delineated by these parameters. A watershed refers to the area enclosed within a drainage boundary. Its shape determines the formation and travel routes of the water in the watershed. There are many descriptive parameters about watershed shape including complexity index, compact index, round index, narrow index, curve index, elongation index, asymmetry index, stream evolution index and so on. A region refers to more macro extent of land surface and its area isn't fixed. The statistics of basic TAs are used to reflect the macro characteristics of landform configuration in a region.

3.2 The classification of TAs based on their calculation methods

The difference of TAs is represented not only in their descriptive spatial extents but also in their calculation methods. Therefore, according to their algorithms, TAs are classified into basic TAs, features TAs, statistical TAs, and compound TAs.

With specific mathematical expression and physical definition such as slope, aspect, curvature etc., the basic TAs can be directly calculated from DEM data. That is, their values are got by differential calculation or surface fitting in a local area for grid DEMs and directly checked by measure on the spot or on relief map. Geomorphologically, there are some basic morphology indexes for landform features, which include the elevation, the shape and area of projected plane, the direction and steepness of surface. They play important roles in the research on geomorphology. The actual elevation and relative elevation determine the types and orders of geomorphology. The division and region planning of geomorphology is based on terrain form and area. And the surface steepness is the main index used to mark off the grade of slope.

TAs Type		Corresponding TAs
Local TAs		elevation, relief, slope, aspect, curvature, plane distance, slope of slope, slope of aspect, terrain shape index, upslope slope, upslope length, dispersal length, flow path length, variance index, differentia index, concave-convex index, flow accumulation
Global TAs	Slope scale	slope shape, slope position, slope length, shape complexity index, slope elevation, shape parameter, slope gradient, slope direction, elongation direction, plane area, surface area, slope volume, fractal dimension
	Watershed scale	complexity index, compact index, round index, narrow index, curve index, elongation index, asymmetry index, stream evolution index, gully density, upslope area, dispersal slope, catchment slope, catchment area, specific catchment area, maximal/minimal catchment area, catchment length, relief amplitude, relief roughness, elevation variation coefficient, cutting depth, slope spectrum, area-elevation graph, mean elevation, difference from mean elevation, standard derivation of elevation, elevation range, derivation from mean elevation, percentage of elevation range, plane area, surface area, fractal dimension, branch ratio
	Region scale	relief amplitude, relief roughness, cutting depth, elevation variation coefficient, gully density, slope spectrum, area-elevation graph, mean elevation, difference from mean elevation, standard derivation of elevation, elevation range, derivation from mean elevation, elevation percentile, percentage of elevation range, plane area, surface area, fractional dimension

Table 1. The classification of TAs based on spatial scale which it describes. (Some TAs refers to a kind of terrain attributes such as curvature, slope shape, and slope position; they are explained in the following text. Some statistical TAs can apply to slope, watershed or region scale.)

Representing the shape characteristics and scraggy change of the slope surface in all directions, slope curvatures can effectively describe the local form and structure of landform features and reflect the kinetic rules of the matters on the surface. Slope curvatures are grouped into two main types and twelve minor ones (Shary,1995; Shary et al., 2002). Only describing geometrical structure of the surface, the curvatures of the first main type are independent of reference coordinates. In contrast, the ones of the second main type have to do with the directions of coordinate systems. Table 2 shows the main information of common slope curvatures.

Describing the terrain features qualitatively, features TAs can be directly gotten from DEMs. In spite of specific definition, they are difficult to express by mathematical formulas as a result of their ambiguous boundary. For example, it is difficult to determine the watershed boundary when dividing the watershed units. Though the land surface is diversiform and complicated, it actually consists of points, lines, and facets. On one hand, they are the frameworks of land surface. On the other hand, they determine the geometrical morphology and direction trends of the landforms. Terrain features can be gotten by their spatial characteristics and relations such as feature points, feature units, hydrological elements, structure lines, visible area and so on. The extraction and analysis of TAs is the basis that marks off geomorphology types automatically and geographical analysis. For instance, there are obvious differences of terrain characteristics, soil erosion modes, and land use types on the border of loess shoulder-line in loess relief.

Statistical TAs are the statistical results of the terrain parameters in a region. That is, they are extracted by the mathematical analysis methods such as correlation, regression, trend surface, clustering. With the change rules and interior relationship of TAs and proper geographical models, the evolution and spatial variance laws of macro terrain can be revealed deeply.

Curvatures types	Curvatures names	Descriptive Geographical themes
The first types (being independent of coordinates systems)	CM (mean curvature)	“Equilibrium” land form state
	CU (unsphericity curvature)	Extent to which land form differs from a sphere
	Cmax (maximal curvature)	Geometrical C-ridges
	Cmin (minimal curvature)	Geometrical C-valleys
	CG (total Gaussian curvature)	Does not change during surface bending
	CTol (total curvature)	Recognition of terrain features
The second types (being dependent of coordinates systems)	CD (difference curvature)	Compares the 1-st and 2-nd mechanisms
	CP (profile curvature)	2-nd accumulation mechanism
	CC (contour curvature)	Movement modes of terrestrial materials
	CPE (profile curvature excess)	Splits flow-line twisting onto two components
	CHE (horizontal curvature excess)	Splits flow-line twisting onto two components
	CR (total ring curvature)	Flow-line twisting
	CA (total accumulation curvature)	Relative accumulation and deflection zones
	CT (tangential curvature)	1-st accumulation mechanism
	CL (longitudinal curvature)	Recognition and extraction of terrain features
	CS (cross section curvature)	Recognition and extraction of terrain features
	CF (flow-path curvature)	Directions of flow-line rotation (clockwise or not)

Table 2. The information of terrain curvatures (CTol, CL, CS, CF don’t belong to the curvature classification systems of Shary [2002].)

TAs Type		Corresponding TAs
Basic TAs		elevation, relief, slope, aspect, curvature, plane distance, slope of slope, slope of aspect, variance index, differentia index, concave-convex index
Feature TAs	Feature Point	peak, pit, ridge, valley, pass, plane, runoff node
	Feature Line	ridge line, valley line, loess shoulder line, coastline, fault line, loess yuan border line, loess mao border line, slope border line, drainage network
	Feature Facet	divergent shoulder, convergent shoulder, divergent backslope, convergent backslope, divergent footslope, convergent footslope, sink, catchment, longitudinal section, cross section, viewshed
Statistical TAs		mean elevation, elevation range, mean aspect, gully density, relief amplitude, relief roughness, cutting depth, elevation variation coefficient, gully density, slope spectrum, area-elevation graph, catchment slope, catchment area, specific catchment area, catchment length, plane area, surface area, slope volume, fractional dimension, branch ratio, terrain shape index, slope shape, slope area, upslope slope, upslope length, dispersal length, flow path length, flow accumulation, complexity index, compact index, round index, narrow index, curve index, elongation index, asymmetry index.
Compound TAs		topographic wetness index, stream power index, sediment transport capacity index, solar power index, shade angle

Table 3. The classification of TAs based on their calculation methods. (Some TAs refers to a kind of terrain attributes such as curvature, slope shape, and slope position; they are explained in the following text.)

Being used to describe spatial change of geographical processes, compound TAs are comprised of some basic TAs according to special relations which are experiential or to do with simple natural mechanism. Compared with basic TAs and feature TAs, compound TAs are called secondary TAs because they can not be extracted from DEMs at first hand. They are important in the application fields and their physical meanings are required to be measured and interpreted in the fields. The compound TAs are related to some basic TAs which are widely used in the fields of soil, hydrology and geomorphology. For example, flow direction is determined by slope steepness; then specific catchment area of upslope is calculated according to flow direction; the skeleton lines of landform features are extracted by specific catchment area. And slope steepness and specific catchment area are the main parameters of the topographic wetness index and stream power index.

3.3 The classification of TAs based on their descriptive themes

Geomorphology features are quantitatively described by their morphologic and structural characteristics. So, TAs are classified into morphologic TAs and structural TAs according to their descriptive themes. Morphologic TAs are used to describe rolling extent of nature elements, including terrain points, terrain lines, and terrain facets factors. Then they are divided into plane morphologic TAs, cross morphologic TAs and vertical morphologic TAs. Structural TAs refer to overall arrangements and combinations of geographical units.

Morphologic descriptions of terrain features are the scientific basis used to compare and analyze their characteristics and types. For polygonal landform features, they are described by their morphologic characteristics of plane section, cross section and vertical sections. With common descriptive factors including diameter, ellipticity, the length of longest axis and shortest axis, curve extent, area, extension property, shape index etc., the plane section is the outline that terrain feature is projected on the plane coordinates. Cross section is the section that cuts the landform feature from the top down along the direction vertical to its extending ones. For positive landform units, the main morphologic indexes include slope shape, slope length, slope steepness, slope mean elevation, symmetry property, the conversion between top sides and slope ones, or slope ones themselves; for negative ones, they include features relief, the widths of bottom sides, the conversion from bottom sides to slope ones and so on. Being the section that cuts the landform feature body from the top down along the features line direction, vertical section can describe the characteristics of linear of zonal landform features. For linear landform features, their morphologic characteristics can be represented by their length, extension direction, curvature, curve number, curve shape, or fractal dimension etc..

TAs Type			Corresponding TAs
morphologic TAs	terrain point		elevation, relief, slope, aspect, curvature, plane distance, slope of slope, slope of aspect, terrain shape index, concave-convex index
	terrain line		length, extension direction, curvature, curve number, fractional dimension
	terrain facet	plane morphology	diameter, ellipticity, the length of major axis and minor axis, curve degree, area, extensibility, shape index
		cross morphology	slope shape, slope length, slope steepness, slope mean elevation, symmetry property, the conversion between top sides and slope ones, the widths of bottom sides, the conversion from bottom sides to slope ones
		vertical morphology	relief amplitude, slope length, extension direction, curvature, curve number, curve shape, or fractal dimension
structural TAs	slope spectrum, ridge network, stream network, the distribution of landform features, area-elevation graph		

Table 3. The classification of TAs based on their descriptive themes.

- Morphologic TAs
  - Slope State TAs
    - slope
    - aspect
  - Slope Shape TAs
    - macro shape (line, convex, concave, terrace slope)
    - transform ratio (slope of slope, slope of aspect)
    - curvature (plane curvature, tangential curvature etc.)
  - Slope Length TAs
    - runoff length
    - whole slope length
  - Slope Position TAs
    - positive position
    - negative position
  - Slope complexity TAs
    - relief amplitude
    - relief roughness
    - cutting depth
    - elevation variation coefficient

Figure 1. The classification of morphologic TAs

TAsMoreover, morphologic TAs are differentiated as slope state TAs, slope shape TAs, slope position TAs and slope complexity TAs. Slope state TAs reveal the incline degrees and directions of slope units. Slope shape refers to concavo-convex morphology in a local point. Slope length has two types that are slope whole length and runoff length. Being one of important indexes in soil and water conversation, the runoff length of a point is the length of the line that maximal ground distance from the source node to itself along the flow direction being projected on the horizontal plane. Slope position reflects where slope unit locates. Including relief amplitude, relief roughness, cutting depth, and gully density etc., slope complexity TAs describe the rolling and fragmentized state in a large-scale region.

3.4 The other classification of TAs

3.4.1 TAs can be labelled as first-order TAs, second-order TAs and multiple-order TAs by partial derivatives degree of elevation data

As we know, the store format of DEMs includes regular grid, surface and spatial polygon. For each type of DEM, it can generate digital terrain model having the same store structure with DEMs by deducing, deriving, and combining. When using DEMs with surface store format, DEM being original function can be regard as monomial digital terrain model which needs not be derived.

Including slope gradient and aspect, first-order TAs is derived from DEMs using first partial derivatives of elevations. Slope of slope (SOS) is derived from slope gradient and slope of aspect (SOA) is derived from slope aspect. Curvature factors such as plane curvature and tangential curvature are derived from DEMs using second partial derivatives of elevations. Being second partial derivatives of elevation z, they are second-order TAs. Both first-order TAs and second-order TAs are simplex. Moreover, there are some multiple-order TAs which are the combinations of original elevation z, first-order TAs and second-order TAs. In actually, first-order TAs and second-order TAs derived from DEMs, they are used to satisfy the needs of geographical analysis and thematic applications on industry and agriculture. At present, the applied values of multiple-order TAs are discussed rarely.

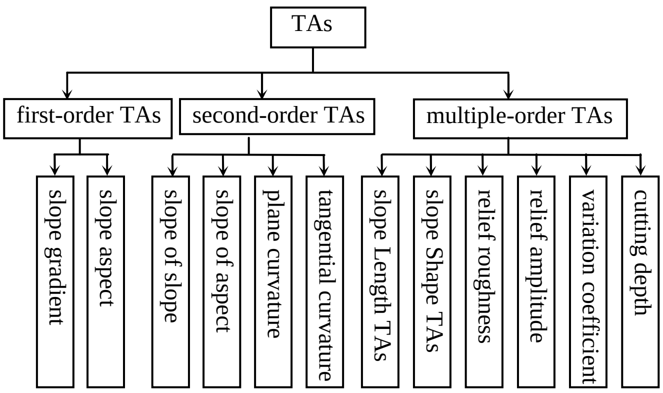

Figure 2. The classification of morphologic TAs based on their derivative degree

3.4.2 TAs are grouped into geometrical TAs, isotropic TAs, axial TAs, and anisotropic TAs on the basis of the relationship of TAs values and coordinate axes direction

The value of a geometrical TA doesn't change when the land surface is rotated as a whole around any axis of given coordinate system (e.g. the surface is inclined). It is independent of specific applied fields and describes the land surface itself, thus ignoring all geophysical vector fields (Gauss, 1827). Such TAs are also isotropic and cannot be axial. They play a special role in digital terrain modelling (shary et al., 2002), and provide an alternative approach to numerous applications. Landforms defined using geometrical TAs have been termed geometrical forms (shary et al., 2002).

The value of an isotropic TA is independent on orientation of rectangular Cartesian plan coordinates x,y.

The value of an anisotropic TA depends on x-coordinate direction. For example, slope aspect and insolation index are anisotropic, because they depend on some geographical direction, such as to the North or to the Sun's azimuth).

The value of an axial TA is isotropic, but its sign depends on the choice of rectangular Cartesian plan coordinates: left or right. Being defined as the curvature of flow-lines that are perpendicular to contour lines on a topographic map, flow-path curvature belongs to one of axial TAs. It is positive when a flow-line turns clockwise and negative in an opposite case (this is valid only for usually used right coordinate systems, for left ones the sign of rot is opposite). Axial TAs are normally described for the commonly used right coordinate system.

Almost all TAs that describe the system "land surface + gravitational field" have been introduced as isotropic or geometrical ones (shary,1995; Florinsky,2005). The only exception is slope direction (aspect), but it is one of components of isotropic two-dimensional vector of elevation gradient. One its component is length of the vector(slope steepness), and another is the vector direction (aspect) that is usually counted as this vector direction (aspect) that is usually counted as this vector azimuth, from the northern direction clockwise.

4. ONCLUSION AND DISCUSSION

On basis of the summary and analysis of the existing classification of descriptive TAs, TAs are classified systematically according to their descriptive spatial scale, their calculation methods, their descriptive themes, their derivative degrees, and the relationships of TAs values and coordinate axes directions in this paper. These classifications reveal the nature characteristics and relationships of TAs and they are not independent. For example, with specific geometrical definition, local TAs based on spatial vector features belong to basic TAs from the view of calculation methods. Besides, global terrain characteristics can be described by the statistical values of these local TAs. Terrain elements such as points, lines, facets, and the map of their spatial distribution are extracted based on DEMs. Then, the morphology and structure characteristics in relation to these terrain elements can be analyzed.

In recent years, the research on geomorphology has converted to theory and experiment from description and experience with the development of production and other subjects. Moreover, it is easy for the quantitative analysis of geomorphology with the application of the new technologies such as electronic surveying and remote sensing and the development and perfection of the methods of digital terrain analysis based on DEM data. So, with the extraction and analysis of TAs, the geomorphology difference will be found and its cause will be explored. Then, by the research on the nonhomogeneity of geologic structure in a region and the intensity difference of the geomorphological process, geomorphology can offer essential datum and parameters for the construction of national defense and the production of industry and agriculture, and the development trend of geomorphology conditions will be forecasted well and truly.

Being parameters of landform morphological characteristics, TAs are the basis of quantitative geomorphologic research and essential indices that differentiate landform types. New morphological attributes are looked for and combined to represent landform characteristics for geomorphologist, geographer and scholars being interest in information all the same. At present, there are two key problems on quantitative analysis of geomorphology. The first one is that quantitative analysis of geomorphology not only reflects the topography characteristics but also reveals geomorphological process. However, in order to solve geographical and geomorphological process by descriptive TAs, the topographical meanings of TAs should be probed deeply now that most TAs only presents geomorphologic shape. Another is that how to design effective global TAs is an important issues needing to solved because of quantitative analysis of global landform shape mostly based on mathematical statistics currently.

ACKNOWLEDGEMENTS

Thanks for financially support from the National Natural Science Foundation of China (No.40571120, 40671148), Specialized Research Fund for the Doctoral Program of Higher Education (No.20050319006) and the National High Technology Research and Development Program of China (2001AA130080, 2006AA12Z212).

REFERENCES

Evans, I.S., 1972. General geomorphometry, derivatives of altitude, and descriptive statistics. In: Chorley, R.J.(Ed.), Spatial Analysis in Geomorphology. Methuen & Co., London, pp. 17– 90, Chap. 2.

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift fuer Geomorphologie N.F., Supplementband 36, 274– 295.

Evans, I.S., Cox, N.J. et al., 1999. Relations between land surface properties: altitude, slope and curvature. In: Hergarten, S., Neugebauer, H.J. (Eds.), Process Modelling and Landform Evolution. Springer, Berlin, pp. 13– 45.

Freeman, T.G., 1991. Calculating catchment area with divergent flow based on a regular grid. Computers & Geosciences, 17, 413– 422.

Gauss, C.F., 1827. Disquisitiones generales circa area superficies curvas. Gott. Gel. Anz. 177, S1761–S1768.

Mandelbrot, B., 1967. How long is the coast of Britain? Statistical self-similarity and fractional dimension. Science, 156, 636–638.

Martz, L.W., de Jong, E., 1988. CATCH: a Fortran program for measuring catchment area from digital elevation models. Computers & Geosciences, 14, 627– 640.

He, C.B., 2007.The Method for Collecting Regional Topographic Factors based on Digital Elevation Model (DEM). Forest Inventory and Planning, 32(2),18-21.

Jochen, S., Allan, H., 2004. Fuzzy land element classification from DTMs based on geometry and terrain position. Geoderma, 121, 243-256.

Ke, Z.Y., He, J.B., Chi, T.H., 1993. *Digital Surface Model*. Chinese Science Technology Press, Peiking, pp. 212-279.

Pennock, D.J., Zebarth, B.J., de Jong, E., 1987. Landform classification and soil distribution in hummocky terrain. Geoderma, 40, 297– 315.

Peter, F., Jo, W., Tao, C., 2004. where is helvellyn? Fuzziness of multi-scale landscape morphometry. Trans. Inst. Br. Geogr, 29,106-128.

Shary, P.A., Sharaya, L.S., Mitusov, A.V., 2002. Fundamental quantitative methods of land surface analysis. Geoderma, 107, 1-32.

Tang, G.A., Liu, X.J., Lv, G.N., 2005. *The principle and method of geographical Analysis and digital elevation model*. Science Press, Peiking, pp. 207-290.

Troeh, F.R., 1964. Landform parameters correlated to soil drainage. Soil Science Society of America Proceedings, 28, 808–812.

Wilson, J. P., Gallant, J.C., 2000. *Terrain Analysis: Principles and Application*. Wiley, New York, pp. 1-28.

Zhang, T., Tang, G.A., Wang, C., et al, 2005. Correlation of Quantitative Terra in Factors in Gully Hill Area s of China Loess Plateau. Scientia Geographica Sinica, 25(4),467-452.

Zhou, Q.M., Liu, X.J., 2006. *Digital Terrain Analysis.* Science Press, Peiking, pp. 6-13.

Zhang, G.S., 2005. *Modern Geomorphology*. Science Press, Peiking, pp. 183-188.