The scale effect analysis of slope length based on DEM multi-scale representation

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ABSTRACT: It's the only way to extract slope gradient and slope length based on low-resolution DEMs for the studies of regional scale soil erosion modeling. But the slope gradient will reduce and the slope length will enlarge. In Xiannangou catchment, a database of DEM is established by using the wavelet multi-resolution analysis method, which has a gradually-changing resolution and a unified position control base, and effective ability in representing the overall topographic characteristics and landform macro structure. On this basis, we deeply reveal that the variation pattern of the slope length increases as the DEM resolution becomes coarser. The results show that, with DEM resolution become coarser, the gully elevation is rising, while the Liang and Mao top elevation are decreasing, and the small-scale gully, Liang and Mao top are gradually disappeared. Average slope length has a linearly increasing trend with the reduction of DEM resolution, and slope length cumulative frequency curve is moving towards larger value. In general, the overall slope length is enlarged, and the enlarging mainly happens in the middle and bottom of slopes.

Keywords: DEM multi-scale representation, wavelet multi-resolution analysis, slope length increase, scale effect of slope length

INTRODUCTION

Slope gradient and slope length are two of the most important terrain indexes which influence soil erosion[1]. These two indexes are normally extracted from DEMs with lower resolution in the research of regional soil erosion. However, slope gradient tends to decrease[2-8] and slope length tends to increase[9] as resolution becomes coarser. These make the calculated slope gradient and slope length not accurate enough to describe the real relief of terrain. Thus the accuracy of hydrology and soil erosion model is declined[8, 10, 11]. At present, the studies on slope gradient decreases are more. For slope length increases, some researchers have paid attention to this phenomenon and its effect, but there are few research reports about scale effect of slope length. Therefore, it has a very important significance for regional scale soil erosion research to study on the rule and mechanism of low-resolution slope length increases.

DEM is the basic data of terrain factor extraction and digital terrain analysis and application[12, 13]. Multi-scale DEM data in the same area have become the basic DEM data source of terrain factor scale effect analysis. And wavelet analysis method with the reputation of "mathematical microscope" is a striking similarity to the basic idea of spatial data multi-scale representation which provides an effective way to analyze and express different resolution DEMs.

METHOD

The study area and base data

The study area locates in Xiannangou Catchment in Loess Hilly and Gully Region in the Loess Plateau. It is a square area with 25km. The area is a typical Loess Hilly-Gully area with complex terrain surface and intensively soil erosion.

The original DEM data is the

Hydrological-correct DEMs (Hc-DEMs)[14, 15] of high resolution (2.5m) generated by 1:10 000 scale digital topographic map using AUNDEM software. In addition, taking the Hc-DEM data with the resolution of 10m, 25m and 50m generated by 1:50 000, 1:100 000 and 1:250 000 scale digital topographic map as reference data. The projection is Gauss_Kruger based on the Krasovsky 1940 Datum.

Wavelet transform and slope length extraction

Wavelets are mathematical functions that decompose signals into different frequency components, and represent each component with a resolution matched to its scale. The elegance of the wavelet multi-resolution analysis of $L^2(R)$ comes from the fact that the scaling functions φ generate a set of nested subspaces V_j of $L^2(R), j \in Z$, while the associated wavelets ψ constitute their orthogonal complementary subspaces W_j, i.e. $V_j = V_{j+1} \oplus W_{j+1}$. $f(x)$ is represented with a set of orthonormal basis in V_{j+1} ($\{\varphi_{j+1}, k \in Z\}$) and W_{j+1} ($\{\psi_{j+1}, k \in Z\}$), i.e.

$$f(x) = \sum_n c_n^{j+1} \varphi_{j+1,n} + \sum_n d_n^{j+1} \psi_{j+1,n} . \quad (1)$$

Here,

$$c_k^{j+1} = \sum_n h_{n-2k} c_n^j , \quad (2)$$

$$d_k^{j+1} = \sum_n g_{n-2k} c_n^j . \quad (3)$$

That is orthogonal wavelet decomposition procedure for discrete signal. Here j are levels of wavelet decomposition; h_{n-2k} is scaling coefficients and g_{n-2k} is wavelet coefficient of a wavelet system, respectively corresponding to low-pass and high-pass filter coefficient.

Since the wavelet transform is a filtering process, it is efficient for wavelet transform to reconstruct the original signal using either de-convolution or the inverse filter. Wavelet reconstruction function is

$$c_n^j = \sum_{k \in Z} h_{n-2k} c_k^{j+1} + \sum_{k \in Z} g_{n-2k} d_k^{j+1} \quad (4)$$

Where c_k^{j+1} is low-frequency component; d_k^{j+1} is high-frequency component; c_n^j is wavelet reconstruction component; h_{n-2k} is low-pass filter coefficient of wavelet reconstruction; g_{n-2k} is high-pass filter coefficient of wavelet reconstruction.

The orthogonal wavelet decomposition and reconstruction equations are theories basis of DEM multi-scale representation when DEM is regarded as a discrete signal.

Since DEM multi-scale representation is a process of filtering partial fractal terrain, and considering such as compactly supported, symmetric, orthogonal , regularity and larger cancellation, we select biorthogonal wavelet function bior4.4. In addition, the Radical Law Selection Principles[16], traditionally feature selection principle used in artificial cartographic generalization, was used to set different scale parameters during the threshold processing on the wavelet high frequency coefficients. i.e.

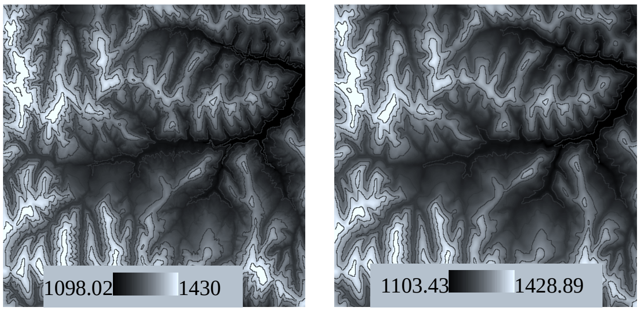
$$N_b = N_a \sqrt{M_a / M_b} \quad (5)$$

Here, N_a and N_b is respectively the number of high frequency wavelet coefficients of 2.5m resolution and derived DEM. M_a is the scale denominator of the source map; M_b is denominator of scale parameters of the derived DEM used in the implement of wavelet transform.

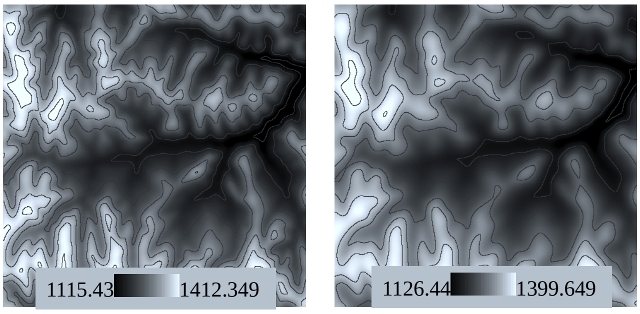
The calculation method of slope length is runoff accumulation algorithm based on the soil erosion principle[17], which flow direction algorithm is used by multiple flow direction algorithms (MS)[18].

RESULTS AND ANALYSIS

A set of DEMs are established by using the wavelet multi-resolution analysis method, which has a gradually-changing resolution and a unified position control base, and effective ability in representing the overall topographic characteristics and landform macro structure. Fig.1 shows the DEM multi-scale representation.



(a) 2.5m original DEM (b) scale parameter 200 000



(c) scale parameter 600 000 (d) scale parameter 1 000 000

Fig.1 DEM multi-scale representation of different scale parameters with wavelet transform

On this basis, we deeply reveal that the variation pattern of the slope length increases as the DEM resolution becomes coarser. Taking the Hc-DEM data with the resolution of 10m, 25m and 50m generated by 1:50 000, 1:100 000 and 1:250 000 scale digital topographic map using ANUDEM software in Xiannannou Catchment as reference data, the paper evaluates the quality of the generated DEMs, which have different scale parameter and obtained by using wavelet transform method using the elevation shannon, playback contours and slope gradient histogram similarity. Then, the relationship between the scale parameter and resolution is established (Fig.2). Hence, the generation of DEMs with arbitrary coarser resolutions is realized.

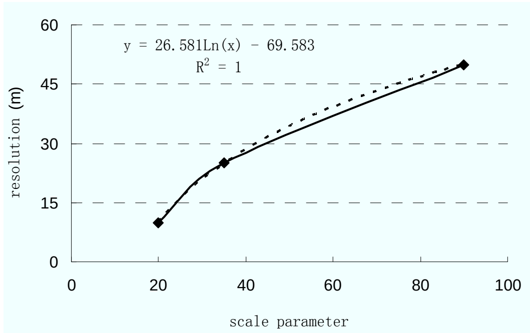


Fig.2 the relationship curve between DEM scale parameters after wavelet transform and DEM resolutions generated by digital topographic map

Based on the multi-resolution database obtained by using wavelet transform, the variation pattern of slope length along with the changing of DEM resolution is analyzed. The results show that with DEM resolution become coarser, the gully elevation is rising, while the Liang and Mao top elevation are decreasing, and the small-scale gully, Liang and Mao top are gradually disappeared. Average slope length has a linearly increasing trend with the reduction of DEM resolution (Fig.3). In general, the overall slope length is enlarged, and the enlarging mainly happens in the middle and bottom of slopes (Fig.4).

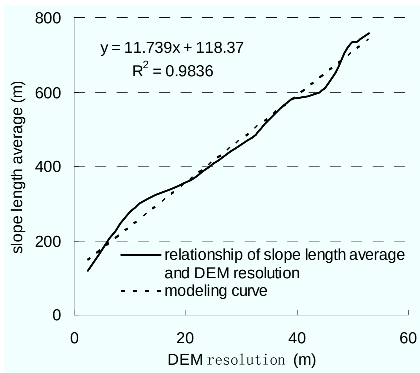
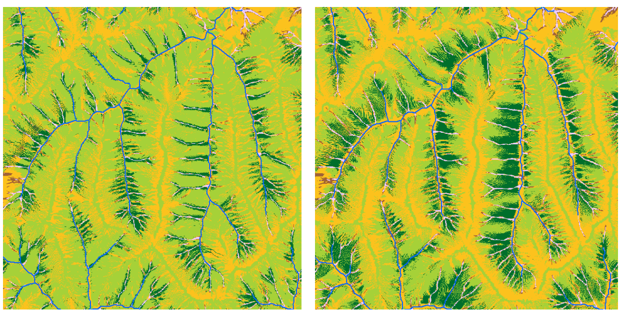


Fig.3 Change trend of average slope length with DEM resolution become coarser



(a) scale parameter 200 000 (b) scale parameter 400 000

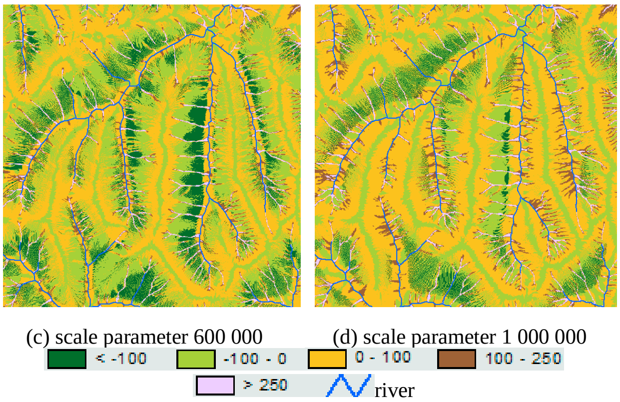


Fig.4 The slope length differential map extracted by DEM of 2.5m resolution and different scale parameter

CONCLUSIONS

With the analyses above, we can conclude that: A database of DEM is established by using the wavelet multi-resolution analysis method, which has a gradually-changing resolution and a unified position control base. Slope length increases along with DEM resolution become coarser and the location of slope length changing is mainly in the middle and bottom of slopes.

DISCUSSIONS

According to this study, slope length on the scale of the DEM resolution has great dependence. Therefore, In large scale range, such as regional scale, it is need to transform slope length extracted from the low resolution DEM to that of the high-resolution with higher accuracy and consistent ability to reflect the terrain relief, so that the Calculated LS factor can be applied for the regional soil erosion evaluation and it has guiding significance for the national soil erosion survey and actual soil and water conservation measures.

ACKNOWLEDGMENT

This study has been financially supported through the projects Estimating Spatially Distributed Slope Length at Watershed for Soil Erosion Assessment (NSFC Project, 41071188) and Study on theoretical distribution model of Slope (NSFC Project, 41301284).

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