

THE PROFILE SPECTRUM OF CATCHMENT BOUNDARY BASING ON DEMS IN LOESS PLATEAU

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Abstract

The research on landform characteristics and classification based on terrain feature is one of the key directions of topography. Since the Digital Terrain Model (DEM) is taken as more and more important data source in terrain analysis, the DEM-based macro terrain factors which are able to reflect the macro terrain relief is in urgent requirement. Previous researches show that a topographic profile can reflect the important features of terrain surface. However, the anisotropy and randomness of a topographic section line limits its application in terrain representation. Therefore, this paper introduces a new conception of catchment boundary profile spectrum which is immune to anisotropy. The Loess Plateau in northern Shaanxi is chosen as the study area and some researches are done to analyze the characteristics and the spatial distribution of the catchment boundary spectrum in different loess landform areas. Several quantitative indices are proposed for the quantitative describe on loess landform. Moreover, comprehensive depiction, measure and graphical demonstration of the loess landform characteristics, landform complexity and the spatial distribution are investigated in the paper. The results show that the catchment boundary spectrum can well describe the characteristics of different loess landform types to a certain extent. The interpolated surfaces of quantitative indices from 48 sample areas indicate more specific spatial distribution information of different loess landforms.

1 . Introduction

The Loess plateau has got world's attention for its unique geographical condition, grand loess landform and special natural and human landscapes. Much work has been done in relation to loess landform. The classification and regionalization of loess landform was investigated based on half-quantificational analysis from points of the structure, erosion and morphological features of the loess plateau. The classification system of the loess landform has been proposed according to the principle of formation and morphology and the developing mode of loess plateau landform has been discussed. The combination of typical loess plateau landform and the distribution pattern was researched. The basic quantitative method for loess landform research has been put forward (Chen, 1956; Luo, 1956, 1998; Yang et al., 1957; Qi and Wang, 1959; Zhang, 1986; Wu et al., 1991).

The topographic research based on DEM grows fast as the development of GIS technology and Digital Terrain Analysis (DTA). The core of DTA is the deprivation of topographic parameters like slope, aspect and curvature etc. The neighbourhood analysis with 3*3 partial-windows is widely used in topographic parameters deprivation of grid DEM and topographic parameters extracted from local cells. These topographic parameters are capable to reveal variation of terrain surface in certain extent; they can hardly identify regional landform types on macro scale. Therefore, it is necessary to find a more integrated terrain index which is not only simple and easy to extract, but also well capable to show the terrain relief characteristics.

New methods for quantization like slope spectrum based on DEMs has been proposed in 2003(Tang et al., 2003). The slope spectrum is regarded as a statistic graph or a mathematical model with its independent variable denoting slope gradient and its dependent variable of the corresponding area on the ground. The extraction way and digital terrain analysis based on slope spectrum has been carried out, and the spatial distribution characteristic was further studied (Tang and Li, 2007).It was investigated that the each Loess landform type corresponding to a unique slope combination-slope spectrum. The slope spectrum analysis using micro terrain factors to research the macro terrain characteristics has been proved effective and a beneficial exploration. Whereas, the data source accuracy, the data processing method and DEM resolution all lead to effect of uncertainties in slope spectrum. Therefore, a more stable and reliable factor is expected to reflect the Loess landforms.

The terrain profile line which directly reflects the terrain relief is widely applied in geography, geology and hydrology. The shape of transverse profiles reflects erosional processes (Schumm et al., 1995; Harbor and Wheeler, 1992). The longitudinal profiles of watersheds have often been linked to erosional power, river-bed sediment and aggradations and tectonics (Lu et al. 1998; Ferguson, 2003; Snyder et al., 2003). Zhou et al. (2006) investigated both transverse profiles and longitudinal profiles of watershed and the mutual relationships between them.

Although series of terrain profile lines, transverse or longitude, can reflect the variation characteristics of terrain surface, the transverse profiles of watershed can not escape from the limitation of anisotropism which leads to randomness and chanciness for decrypting the landform variation. Meanwhile, the longitudinal profile of gully is hard to reveal the relief of positive terrain like loess yuan, loess ridge and loess hillock.

On the basis of former researches above, this paper introduced a brand-new concept of catchment boundary profile spectrum. The profile line of catchment boundary is capable to obtain through certain program. The catchment boundary spectrum is defined as a series of catchment boundary profile lines in different landforms and catchment scales. For analysis, the spectrum starts from the outlet point of catchment, goes along with the catchment boundary and finally goes back to the outlet point. The catchment boundary profile spectrum is convenient for analysis, which makes it feasible as the research object in this paper.

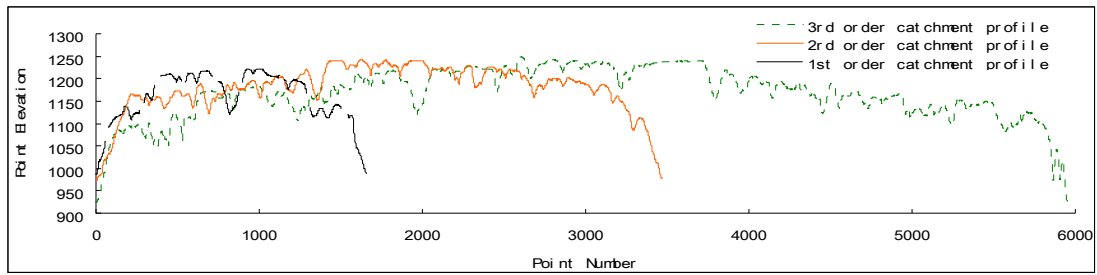


Figure 1 A set of catchment boundary spectrums in the same sample area

2. Test area

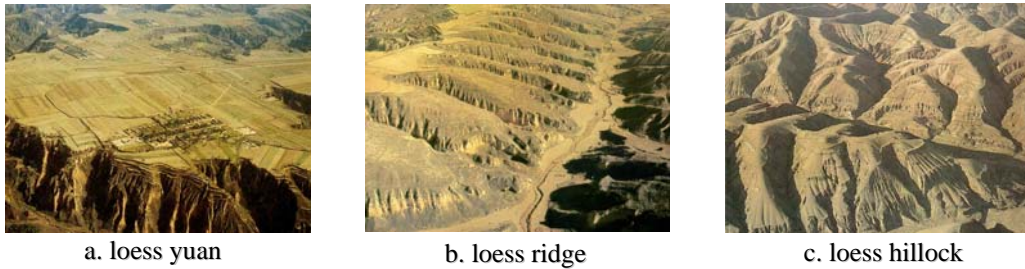


Figure 2 Three typical landforms in Loess Plateau

The Loess Plateau is located in the middle reaches of the Yellow River (the Huanghe River). It is the most widely distributed region of the loess on the Earth, where the thickest loess-paleosol sequence has been developed. With an altitude of 1000-1600 m, it is characterized by various geomorphologic units, including high plain with deep-cutting gully, hilly gully, rock mountain, wide valley plain, and sand-depositing land. The main types of positive landforms in Loess Plateau is loess Yuan, loess ridge and loess hillock. Loess Yuan is loess upland with a flat top and is incised by streams around (Fig2.a). Loess yuan suffer little from modern erosion and is the main plowland on loess plateau. Loess ridge is strip-shape upland in loess plateau (Fig2.b). It was formed from loess covered on the ancient landform of ridge and was eroded by fluviation. Loess hillock is usually referred to a single loess hill (Fig2.c). Most of the loess hillock was formed as the result of further erosion and incision of loess ridge. The relation among loess yuan, loess ridge and loess hillock represent the landform evolution process on loess plateau.

The original landform elevations were obtained from digitized contour maps that cover the whole northern Shaanxi Loess Plateau. The dataset of test areas including 6 typical research areas and 48 spatial distribution research areas are DEMs with 25 m grid size (Fig.3). Some general statistics parameters of six typical test areas are listed in Table 1.

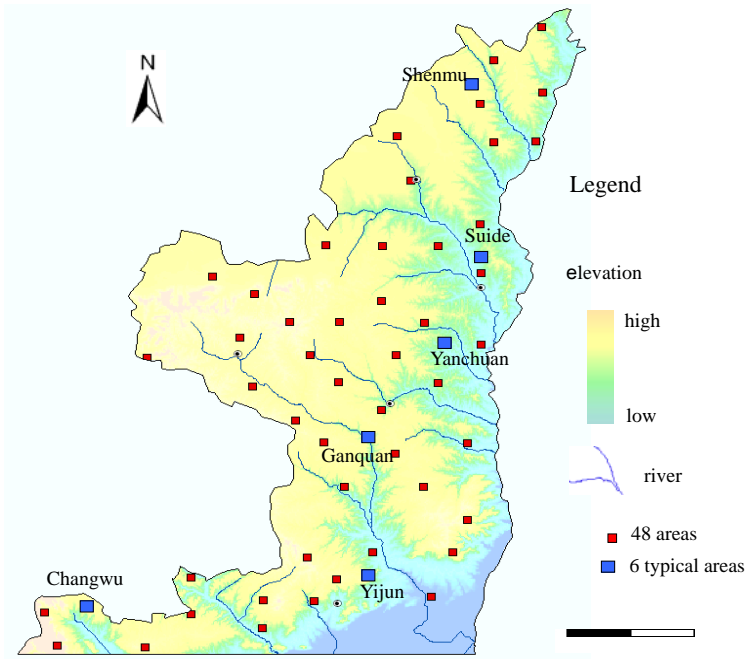


Figure 3 The map of test areas in Loess Plateau

Statistics	Shenmu	Suide	Yanchuan	Ganquan	Yijun	Changwu
Mean	1234.01	1049.78	1188.38	1366.56	1031.37	1113.83
Median	1249.22	1054.73	1204.83	1373.56	1032.28	1186.63
Maximum	1313.13	1123.25	1249.48	1452.67	1112.86	1202.22
Minimum	1089.90	872.89	977.73	1149.34	832.23	905.89
Range	223.86	251.88	271.81	302.72	279.54	296.72
Std.	49.08	37.62	53.62	54.65	54.29	113.96

Table 1 statistics information of six text areas

3. Methodology

3.1 Extraction of catchment boundary spectrum

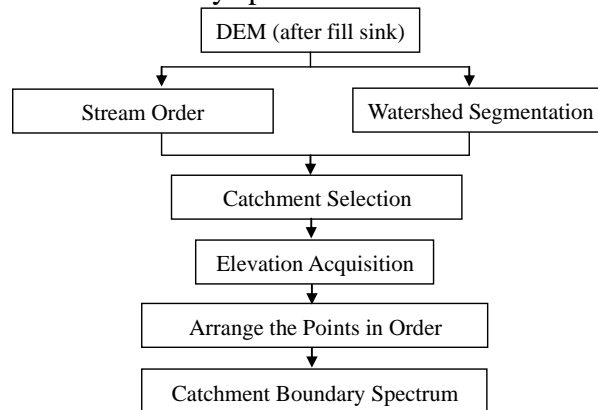


Figure 4 the extraction process of catchment boundary spectrum

In this paper, the catchment segmentation was completed using ArcHydro Tool. Figure 4 shows a procedure for extracting catchment boundary spectrum from DEMs. There follows a few key points in this process.

1) Since the number of stream order in most test areas is 3, the boundary of the 3rd order catchment usually go beyond the test area. In this paper, the catchment corresponding to the 2nd order stream (According to Strahler Stream Order) is selected as the typical catchment.

2) Use tool 'Feature to 3D' from '3D Analyst' menu in ArcMap to add the elevation value of each sample point on catchment boundary onto the catchment boundary line, then export the elevation value as ASC file. Arrange the points from outlet to outlet in clockwise order with programs.

3.3 Quantitative Indices

The profile spectrum of catchment boundaries were extracted using ArcGIS software. Six quantitative indices were proposed including the amplitude, frequency, wavelet entropy, entropy of high and low frequency coefficients, kurtosis of high frequency coefficients to form a integrate quantitative analysis system of catchment boundary spectrum. Calculation methods for the indices are listed in Table 2.

3.2 The quantitative research of catchment boundary spectrum

1) The indices based on frequency

The frequency of catchment boundary spectrum is the ratio of wave crest and wave trough to the sample number. This index is expected to reflect the terrain roughness, while the amplitude can reveal the incision intensity on drainage divide.

2) The indices based on wavelet decomposition

Because of the high ability of detail analysis, the wavelet analysis was introduced into the quantitative research of catchment boundary spectrum. In figure 5, the kurtosis of wavelet high frequency coefficient accurately reflects the difference in different Loess landform types.

Name of Index	Formulations and variables
Frequency (F)	$F = \frac{(N_f + N_g)}{N}$ <p>F is the frequency of wave crest and wave trough of catchment boundary spectrum, N_f is the number of wave crest, N_g is the number of wave trough, N is the sum of sample points</p>
Amplitude (W)	$W = \sum \left(\frac{S_i - \frac{(S_{i-1} + S_{i+1})}{2}}{N} \right)$ <p>S_i, S_{i-1}, S_{i+1} respectively referred to the elevation of sample point i, sample point $i-1$, sample point $i+1$, N is the sum of sample points</p>
Wavelet Entropy (E)	$E = \sum P_k \lg P_k$ <p>After the 3D data of catchment boundary $f(n)$ was decomposed through j levels, the probability distribution of wavelet coefficients is $P_k : P_k = E(j,k) / E$</p>

Table 2 Algorithms for catchment boundary profile spectrum indices

3) Spatial distributions of quantitative indices

The quantitative researches above mainly focus on the description of quantitative indices in most representative Loess landforms and ignore the spatial relationship of loess landform type. In fact, everything is related to everything else, but near things are more related than distant things (Tobler, 1970), different types of landform affect each other and there exist transition zone between them. To verify the point above, the amplitude and wavelet entropy of catchment boundary of 48 test areas uniformly selected in Loess plateau were calculated. The spatial distribution map was generated using Kriging interpolation method.

4. Results

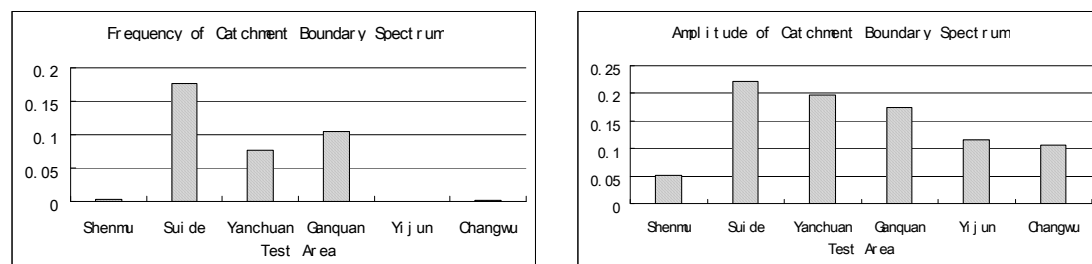


Figure 4 The quantitative indices on frequency in 6 typical test areas

4.1 Analysis on quantitative indices

The frequency of 6 typical test areas is shown in Figure 4. In aspect of landform development, Yijun and Changwu which is Loess Yuan landform are in the early period of development. The erosion on surface is not serious and the gully is not well-developed. The catchment boundary mainly locates on the flat surface, the frequency of catchment boundary profile spectrum is relatively low. Yanchuan and Ganquan which belong to Loess hilly and gully are seriously eroded and the frequency of catchment boundary profile spectrum is higher. Sui de, which also belongs to Loess hilly and gully landform, is in later period of landform development. The frequency in Sui de is much higher than in other test areas. Shenmu in Aeolian-loess transition area has smooth relief and result in low frequency. It can be investigate that the frequency of catchment boundary spectrum can reflect the quantitative feature of peaks, saddles, concave ridges and inclined ridges on drainage divide. However, the frequency of catchment boundary spectrum is just a lateral reflection of landform.

The amplitude of catchment boundary spectrum can reveal the incision intensity of catchment boundary. The amplitude in 6 typical test areas was calculated using the

formulation in table 1. The value of amplitude first increases from Shenmu to Suide, then reduces from Suide to Changwu and this is accord with the fact that real spatial variation of Loess Plateau morphology. Therefore, amplitude intensity of catchment boundary profile can indirectly reflect the land type of certain catchment.

The kurtosis of wavelet high frequency coefficient in 6 sample areas is positive which show the high frequency data signal in Loess catchment incline to be centralized. However, the intensity of centralization is different in different areas. The landform of Yijun and Changwu is loess yuan, the catchment boundaries of these two areas locate on flat surface and the elevation is intensively centralized which lead to the high value of kurtosis. The second highest value occurs in Shenmu. The other 3 kurtosis value is quite close but still follows the descendent sequence from Maturity to old age. It can be concluded that the kurtosis can accurately describe the landform in different developing period.

In order to reflect the complexity of the catchment boundary spectrum more correctly, two types of wavelet entropy was calculated in the paper. The first one involves all the wavelet coefficients of nodes on the bottom level of wavelet decomposition. The second one is the wavelet entropy of high-frequency coefficients. Along with wavelet entropy and wavelet entropy only of high frequency coefficients, 6 typical loess landforms can be distinguished from each other.

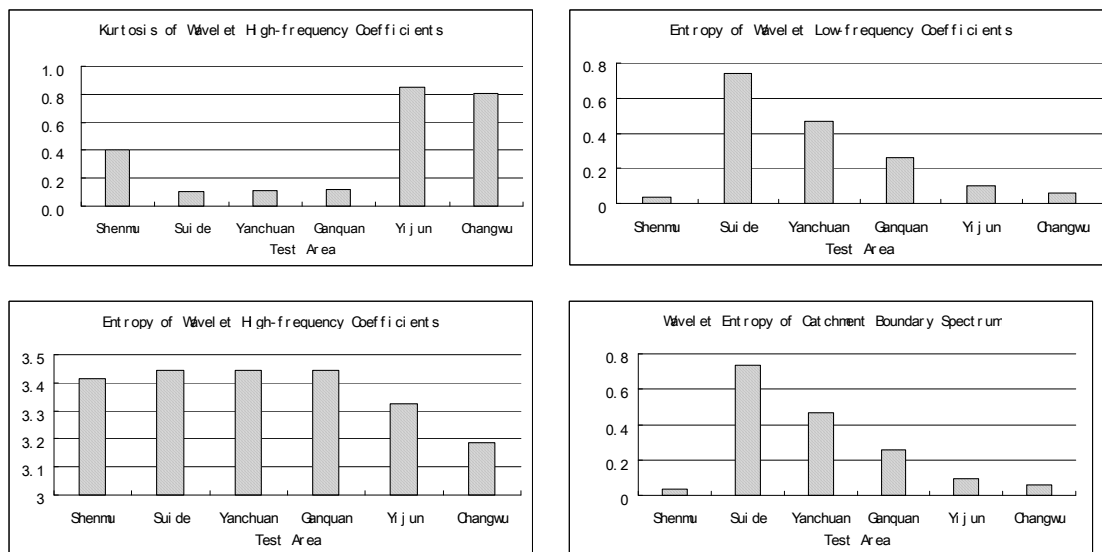


Figure 5 The quantitative indices in 6 typical test areas

4.2 Analysis on spatial distributions

1) The spatial distribution of amplitude

The spatial distribution of amplitude is shown in Figure 6. In general, the value shows a low-high-low trend divided by isolines 0.14 in both south and north. The landform of area to the north of north isoline 0.14 is Aeolian geomorphology. The value reaches minimum in the northwest and has corresponding relation with wind erosion. The

landform of area to the south of isoline 0.14 in south is flat loess yuan and the value goes higher along S-N strike. The main reason of this phenomenon is that the north part is close to the area with rough surface as result of seriously erosion while the landform of south is loess yuan with smooth surface. The area between 2 isolines 0.14 is seriously suffers from erosion and the landform is loess-ridge and hill in the late period of landform development. The buffer area around 2 isolines is transition zone with mixed landforms.

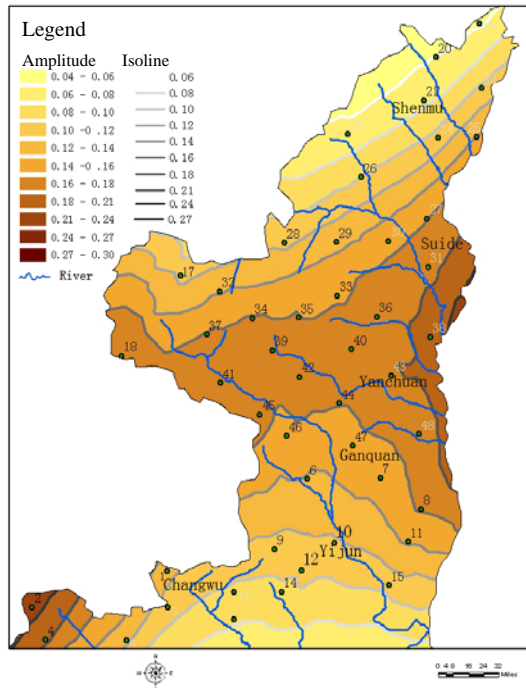


Figure 6. The spatial distribution map of the amplitude of catchment boundary spectrum

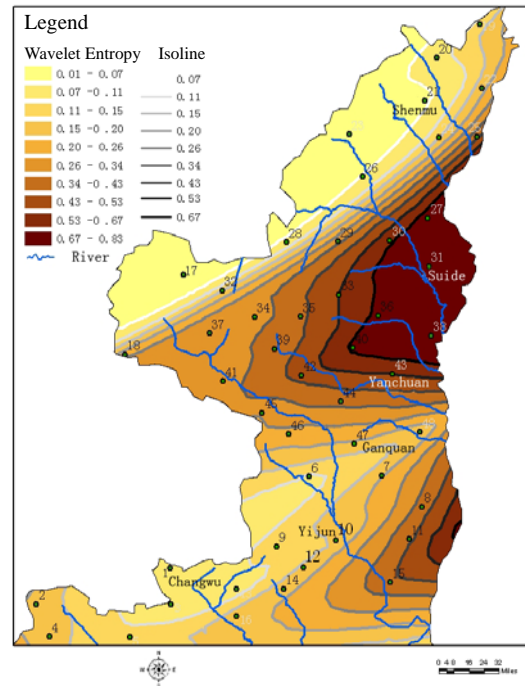


Figure 7. The spatial distribution map of the wavelet entropy of catchment boundary spectrum

2) The spatial distribution of wavelet entropy of catchment boundary profile spectrum
 The spatial distribution of wavelet entropy is shown in Figure 7. The isoline 0.27 divides the map into landforms of sand-covered loess hilly, loess hilly and gully and loess yuan. The minimum occurs in sand covered loess hilly north to the isoline 0.07. In this area, the main landform type is Aeolian gully and the surface is quite mild and uniform, the terrain complexity is small too. From isoline 0.07 to isoline 0.26 in the north of middle part of the map, the dominant landform type is Aeolian loess landform. In general, this area is a special zone evaluated from loess hill and gully. This area is adjacent to desert, the rainfall reduces and the erosion from fluviation is weakened, which lead to the dominance of Aeolian deposition and erosion. Although the ancient underlying terrain is hilly and gully landform, result from the Aeolian effect, the surface becomes smooth again and the terrain complexity becomes low, lead to a low wavelet entropy value of catchment boundary.

The area between 2 isolines 0.27 is in the late development period of loess hilly and gully landform, the erosion is very strong, result in the highest wavelet entropy of catchment boundary in the whole Loess Plateau.

The entropy in the middle loess hilly and gully increase from west to east and reaches the maximum in Yellow river valley in the east. This area is surrounded by isoline 0.67, the main terrain type is loess hillock hilly and gully in the late evolution period, hillock-ridge hilly and gully and Yellow river canyon.

The wavelet entropy in southeast to sample areas of No.8, No.11 and No.15 is relatively high. This is because Huanglong Mountain locates in this area, which leads to a rough terrain surface and a high wavelet entropy value. This information is missing in the spatial distribution map of the amplitude of catchment boundary spectrum.

The district between isoline 0.67 and isoline 0.35 is a transition zone from loess hillock hilly and gully to loess ridge hilly and gully. Around isoline 0.26 there are some loess ridge hilly and gully, from isoline 0.34 to 0.26 belong to loess ridge hilly and gully. South to isoline 0.26, the surface is Loess Yuan. The gully keeps extending in to the surface of loess yuan as a result of active erosion.

It can be investigated that the entropy value of wavelet decomposition has a more exact corresponding relationship with the spatial variance of terrain types in direction of south to north.

5. Conclusion

The research first proposes the catchment boundary profile line as one of the feature line to reflect the characteristics of Loess landform and distinguish the Loess landforms types. The quantitative indices including the frequency, amplitude, high frequency coefficient and entropy of wavelet decomposition of catchment boundary are introduced to quantize and describe the catchment boundary geomorphology. The combined analysis of the indices can reflect the different terrain types in Loess plateau.

The spatial distribution map of amplitude and the wavelet decomposition entropy of catchment boundary can both show the spatial distribution characteristics and mutual relation of Loess landform types. It is shown that the regular change not only appear in direction of south to north, but also in east to west.

Because of the data restriction, the accuracy of the spatial distribution has been affected. More test areas and further study will be done in this field. The quantization and distinguish result of typical Loess landform types like loess Yuan, loess hill-ridge and loess hillock is relatively better, while the value of quantitative indices in loess low hill and loess Yuan are quite close, the difference between them only appears a bit

more significantly in the high-frequency wavelet entropy, the stability and reliability of this difference will be researched in further study.

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