Postprint: Classification of Typical Loess Landforms Based on Sub-watershed Units

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Abstract

Automatic classification of digital geomorphological morphological types based on grid DEM is currently an active research area in geomorphology. According to the granularity of the basic analysis unit, existing classification methods can be divided into those using raster cells as the analysis unit and those using irregular slope polygons as the analysis unit. However, both approaches inevitably exhibit the problem of incomplete geomorphological entities in their classification results. This paper advances the analysis unit to the small watershed level, proposing a classification concept that takes micro-scale sub-watersheds at the "cell" level as the analysis object. Utilizing GIS spatial analysis methods, a geographical attribute database for sub-watersheds is constructed. Based on existing geomorphological data of the study area, four core classification indicators are selected: elevation, relief amplitude, average slope, and slope spectrum skewness. Employing a hierarchical classification method and setting corresponding thresholds for topographic factors, Yaozhou District, Tongchuan City, Shaanxi Province is divided into eight major types: floodplain, loess residual tableland, loess platform tableland, steep gully, ridge-hill shaped loess hilly-gully, rocky small-relief gentle middle mountain, rocky small-relief steep middle mountain, and water body. The classification results maximize the preservation of relative integrity of geomorphological entities. Comparative analysis with field sampling observations conducted using GPS demonstrates that the classification accuracy of this scheme reaches 88.19%, representing a beneficial exploration for digital geomorphological classification research based on sub-watershed units.

Full Text

Preamble

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Abstract

In this paper, the analysis units were upgraded to the minor drainage basin level, and the subcatchments of the micro-scale oriented to the "cell" level were proposed as the classification idea of analysis object. The GIS spatial analysis was used to construct the geographic attribute database for subcatchments based on the available geomorphic data of the study area. Four key classification indicators including the elevation, relief degree of land surface, average slope and slope skewness were selected. The hierarchical classification method was used to set the thresholds of the corresponding topographic factors, and 8 types of landforms, i.e. the floodplains, residual loess tableland, loess platform, steep-slope gully, girder-like hilly gully, small rocky undulating temperate mid-mountain, small stone undulating steep-mountain and waters in Yaozhou District of Tongchuan City, Shaanxi Province were divided. The relative integrity of the landforms was maintained in the classification as much as possible. Compared with the field sampling observations performed by GPS, the classification accuracy of the study was as high as 88.19%, which is expected to be a digital geomorphological classification based on subcatchment.

Keywords: subcatchment; landform classification; drainage basin; grid DEM; Tongchuan; Shaanxi

1 Introduction

Yaozhou District is located in Tongchuan City, Shaanxi Province, between 34°50 ∼35°20 N and 108°34 ∼109°06 E, with a total area of 1613.64 km^2 and elevation ranging from 543 m to 1712.50 m. The terrain is characterized by a typical loess hilly-gully landscape with a gully density of 1.19 km·km ^{2} and serious soil erosion. The study utilized 25 m resolution DEM data at a scale of 1:50,000, processed using ArcGIS 10.4 software. The methodological framework involved GIS spatial analysis to construct a geographic attribute database for subcatchments, focusing on four key indicators: elevation, relief degree, average slope, and slope skewness. A hierarchical classification approach was employed to establish thresholds for these topographic factors, enabling the division of the landscape into distinct geomorphic units while preserving their relative integrity.

2 Methods

2.1 Data Sources and Processing

The primary data source consisted of 25 m resolution DEM data (1:50,000 scale) for the study area. Using ArcGIS 10.4, the DEM was pre-processed to fill sinks and generate a seamless elevation surface. The "hydrology" module was applied to extract drainage networks and delineate subcatchment boundaries, which served as the fundamental analysis units. This approach represents a significant improvement over traditional pixel-based or watershed-level analyses, as subcatchments capture more detailed topographic information while maintaining geomorphic continuity.

2.2 Extraction of Geographic Attributes

Four classification indicators were systematically extracted for each subcatchment:

1. **Elevation**: The mean elevation value was calculated from the DEM for each subcatchment unit, providing a primary stratification parameter.
2. **Relief Degree**: This was computed as the elevation difference between the highest and lowest points within each subcatchment, characterizing the amplitude of terrain variation.
3. **Average Slope**: The mean slope gradient was derived from the DEM' s slope map, representing the overall steepness of the subcatchment surface.
4. **Slope Skewness**: This statistical parameter was calculated using the formula:

$$\text{Skewness} = \frac{\sum_{i=1}^{n}(P_i - \bar{P})^3}{n \cdot \sigma^3}$$

where P_i represents individual slope values, $\bar{P}$ is the mean slope, σ is the standard deviation, and n is the number of grid cells (n = 30). Skewness characterizes the asymmetry of slope distribution, with positive values indicating a predominance of gentle slopes with few steep areas, and negative values suggesting the opposite pattern.

2.3 Classification System and Threshold Determination

Based on established geomorphological research in the Loess Plateau region, a hierarchical classification system was developed. The thresholds for each topographic factor were determined through analysis of frequency distributions and consideration of the study area' s specific landscape characteristics. The classification hierarchy prioritized elevation as the primary divider, followed by relief degree, average slope, and finally slope skewness for fine-tuning. This approach ensured that the resulting landform units maintained both statistical distinctiveness and geomorphic logical consistency.

2.4 Validation Methodology

To assess classification accuracy, 127 GPS sampling points were collected across the study area through field observations. These points were randomly distributed across different geomorphic units, with each point' s actual landform type recorded based on field characteristics. The GPS coordinates were overlaid with the classified map to calculate the confusion matrix and overall accuracy.

3 Results

The classification resulted in eight distinct landform types in Yaozhou District: floodplains, residual loess tableland, loess platform, steep-slope gully, girder-like hilly gully, small rocky undulating temperate mid-mountain, small stone undulating steep-mountain, and water bodies. The spatial distribution of these units reflects the region' s complex geomorphic evolution under fluvial erosion and tectonic influences.

Validation using the 127 GPS sampling points demonstrated a classification accuracy of 88.19%. The confusion matrix revealed that most misclassifications occurred between adjacent geomorphic categories with transitional characteristics, such as between loess platform and residual tableland, or between different gully types. This level of accuracy is considered robust for regional-scale geomorphological mapping and demonstrates the effectiveness of the subcatchment-based classification approach.

The high accuracy can be attributed to several factors: the use of subcatchments as analysis units preserved natural geomorphic boundaries; the four selected indicators effectively captured the essential topographic characteristics; and the hierarchical threshold method reflected the actual stratification of landforms in the loess landscape.

[Figure 1: see original paper]
[Figure 2: see original paper]
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[Figure 4: see original paper]
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4 Discussion

The subcatchment-based classification method offers several advantages over traditional approaches. First, it bridges the gap between pixel-level detail and watershed-level generalization, providing an optimal scale for geomorphic analysis. Second, by using integrated units rather than individual pixels, the method reduces noise and produces more coherent landform units. Third, the approach is highly transferable and can be adapted to other regions with similar landscape characteristics.

The 88.19% accuracy achieved in this study compares favorably with previous landform classification studies in the Loess Plateau region. The methodology provides a reproducible framework for digital geomorphological mapping that can support various applications, including soil erosion modeling, land use planning, and ecological restoration.

5 Conclusion

This study demonstrates that subcatchment-based classification using DEM-derived topographic attributes is an effective method for digital geomorphological mapping in loess hilly-gully regions. The four-indicator hierarchical approach successfully delineated eight major landform types in Yaozhou District with high accuracy. The methodology preserves geomorphic integrity while providing objective, reproducible results. Future research should explore the integration of additional environmental variables and the application of machine learning techniques to further improve classification precision.

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Note: Figure translations are in progress. See original paper for figures.