Fluvial Geomorphic Parameters of the Northern Piedmont of Zhongtiao Mountain and Their Neotectonic Implications (Postprint)

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Abstract

Based on Digital Elevation Model (DEM) and Geographic Information System (GIS) technologies, river geomorphic parameters including stream gradient index, channel steepness index, and hypsometric integral were systematically extracted and analyzed for the northern piedmont of Zhongtiao Mountain. The study reveals that the stream gradient index, channel steepness index, and hypsometric integral exhibit relatively high values in the area from Yongji to Jiezhou. Comprehensive analysis of factors such as lithology, precipitation, and tectonics indicates that neotectonic movement is the primary factor controlling the development of river landforms on the northern piedmont of Zhongtiao Mountain, showing an overall strengthening trend from north to south, with the strongest activity south of Yongji. Previous studies have shown that the northern piedmont fault of Zhongtiao Mountain has been tectonically active since the Late Quaternary, with multiple events still occurring during the Holocene, but with varying intensities at different sections. The slip rate of the Jiezhou segment since the late Late Pleistocene is higher than that of the Hanyang and Xiaxian segments, with extremely high values appearing in the area south of Yongji. Evidently, the intensity of neotectonic movement on the northern piedmont of Zhongtiao Mountain obtained from river geomorphic parameters is consistent with the activity intensity of the fault since the Late Quaternary.

Full Text

Preamble

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1 Introduction

Based on Digital Elevation Model (DEM) and Geographic Information System (GIS) technologies, this study extracts and analyzes geomorphic parameters including stream length-gradient index, channel steepness index, and hypsometric integral in the northern piedmont of the Zhongtiao Mountains, Shanxi Province. The study area elevation ranges approximately 5000 m, with relative relief of about 400 m. Previous research indicates that the northern Zhongtiao Mountain Fault exhibits clear neotectonic activity, forming a distinct topographic contrast between the mountainous area and the Yuncheng Basin [**?**, **?**].

Field investigations reveal that the fault zone controls the development of the drainage system. Using 25 m resolution DEM data, we extracted topographic parameters including slope, aspect, and relief. The study area spans approximately 130 km along the fault strike, trending NE-SW with a dip direction of NW and dip angles of 60°–80°. Using ArcGIS and MATLAB, we calculated geomorphic parameters for 73 river segments (R1–R73) and their corresponding watersheds (S1–S73) to quantify neotectonic activity.

The watersheds were delineated based on topographic divides, with each river segment' s watershed numbered correspondingly. Field geological surveys were conducted to verify the accuracy of DEM-derived parameters and to identify fault scarps, knickpoints, and other tectonic geomorphology features [**?**, **?**]. Previous studies have documented Holocene paleoseismic events along the fault, with vertical slip rates varying along strike [**?**, **?**].

2 Data Sources

The DEM data were derived from 1:50,000 topographic maps with a spatial resolution of 25 m. A total of 73 river segments were extracted from the northern piedmont area, numbered sequentially from north to south as R1, R2, ···, R72, R73. Correspondingly, their watersheds were delineated and labeled S1, S2, ··· , S72, S73. Using ArcGIS and MATLAB platforms, we calculated the stream gradient index (SL index) for each segment and analyzed its spatial distribution pattern to infer relative tectonic activity levels.

3 Methods

3.1 Stream Gradient Index

The stream gradient index (SL index), proposed by Hack [**?**], is calculated as:

$$SL = \left(\frac{\Delta H}{\Delta L}\right) L$$

where $\Delta H/\Delta L$ represents the slope of a specific river reach, and L is the length from the watershed outlet to the midpoint of that reach.

In practice, we first extracted the longitudinal profile of each river using DEM data in ArcGIS. The river profiles were then segmented at 100 m intervals to compute local gradients. The SL values were calculated for each segment and averaged to obtain the mean SL index for the entire river. This method effectively captures anomalies in river profiles caused by tectonic uplift, as active faulting typically produces characteristic knickpoints and anomalously high SL values.

The spatial distribution of mean SL values for all 73 rivers shows a systematic increase from north to south (Figure 3). Most SL values fall within the range of 0–500, with an average of approximately 330. Only about 5% of rivers exhibit SL values exceeding 1000, which are predominantly distributed in the southern segment between Yongji and Haizhou, where the fault activity is most intense.

4.2 Knickpoint Analysis

Knickpoints represent locations of abrupt changes in river gradient, often indicating adjustments to tectonic uplift or base-level changes. In the study area, knickpoints are densely distributed south of Haizhou but occur sporadically north of it. This pattern suggests differential uplift rates along the fault strike.

Historical records and previous studies indicate that the fault segment between 1960–1990 showed moderate activity [?]. The concentration of knickpoints in the southern section reflects stronger recent tectonic forcing, while their scattered distribution in the north suggests relatively stable conditions. Field observations confirm that knickpoints in the southern segment often coincide with fault scarps and bedrock outcrops, whereas those in the north are primarily associated with lithological contacts.

4.3 Uplift Rate Estimation

Long-term uplift rates can be estimated from fluvial incision rates. Previous studies have constrained the average incision rates for different time intervals: 0.23 $\mathrm{mm \cdot a^{1}}$ since 13 ka BP [?]; 0.7–0.9 $\mathrm{mm \cdot a^{1}}$ for Holocene terraces [?]; and 0.22–0.55 $\mathrm{mm \cdot a^{1}}$ for late Pleistocene surfaces [?]. These rates demonstrate spatial variation, with the highest values occurring in the southern fault segment.

The consistency between geomorphic parameters (SL index, knickpoint distribution) and measured incision rates confirms that tectonic uplift is the primary control on landscape evolution in the northern piedmont of the Zhongtiao Mountains. The fault slip rate, a key indicator of fault activity, shows a clear north-south gradient, with the maximum values near Yongji corresponding to the highest geomorphic indices.

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Abstract

Based on the Digital Elevation Model and Geographic Information System technology, we extract and analyze the geomorphic parameters which includes stream length-gradient index, channel steepness index and hypsometric integral of the northern piedmont of the Zhongtiao Mountain, Shanxi Province, China. The results showed that the values of stream length-gradient index, channel steepness index and hypsometric integral index were increased gradually from north to south in general and the high values of the parameters were all distributed in the south part between Yongji and Haizhou. The knickpoints which represent the spatial or temporal adjustment of tectonic movement are densely distributed in the part south of Haizhou whereas in the part north of Haizhou the knickpoints were distributed sporadically. Comprehensively analyzing the main factors including rocks, precipitation and tectonics that affect geomorphic parameters, we reached the conclusion that tectonics is the major factor that controls the development of the watershed topographic features and the tectonic activity was increased gradually from the north to the south. The northern piedmont tectonic activity of the Zhongtiao Mountain is mainly controlled by the northern Zhongtiao Mountain Fault according to regional geological tectonic background. The field geological investigation combined with previous studies show that the north Zhongtiao Mountain Fault can be divided into the south section, the middle section, and the north section according to their different geometric trending and fault activities by Xiyaowen village and Mohe village. Fault slip rate which is an important index to judge fault activity in the middle section is higher than that in the south and the north sections and the maximum value is distributed in the south of Yongji. The tectonic activity of the northern piedmont of Zhongtiao Mountain gained from geomorphic parameters is consistent with the fault activity since the late Quaternary. In the north section, as the weak fault activity, we can see the flat pediment which is retreated by the long-term erosion of the Zhongtiao Mountain is as wide as 10 km. However, in the middle section, steep mountain landforms are formed due to the constant strong tectonic activity, and they become more and more striking from the north to the south. The highest peak Snow Mountain which is located at the south of Yongji shows that in this part the fault is the most active, and this is consistent with the high value obtained from geomorphic parameters. Utilize the river geomorphic parameters as the study objects of the tectonic activity can effectively reflect the regional tectonic movement. It provides a new perspective for discussing the relative activity strength in river drainage.

Keywords: the northern piedmont of the Zhongtiao Mountain; river geomorphic parameter; neotectonic movement