Spatiotemporal Evolution of Cultural Sites on the Tibetan Plateau Since the Holocene and Their Driving Mechanisms

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Date: 2019-09-02T00:00:00+00:00

Abstract

The Tibetan Plateau constitutes one of the most geographically distinctive regions globally. Investigating the spatiotemporal evolution of cultural sites on the Tibetan Plateau since the Holocene and its underlying causes holds significant importance for understanding human responses and adaptations in extreme environments. Utilizing ArcGIS spatial analysis, this study examines the spatiotemporal evolution of 14,339 cultural sites on the Tibetan Plateau since the Holocene through geostatistical methods including kernel density estimation, average nearest neighbor index, and global spatial autocorrelation. The results demonstrate that: the nearest neighbor indices across all periods are less than 1, with global Moran' s I values ranging between 0 and 1, indicating positive spatial autocorrelation and a clustered distribution pattern among the sites; the distribution centroid of sites has undergone a transformation from the plateau interior (Paleolithic period) to southeastern marginal valleys (Neolithic period) and subsequently to the eastern region (since the Bronze Age); the morphological characteristics of distribution have evolved through the uniformly widespread type (Paleolithic period), marginal valley type (Neolithic period), valley-clustered type (Bronze Age), degenerated dispersed type (Tubo tribal period), semi-lunar widespread type (Tubo dynasty period), patchy widespread type (Yuan Dynasty), to contiguous clustered type (Ming and Qing Dynasties); the spatiotemporal distribution evolution of sites across various periods on the Tibetan Plateau results from the combined effects of natural environmental factors including altitude, climate change, and vegetation, as well as socioeconomic factors such as production modes, technology, warfare, population migration, and political policies.

Full Text

Spatiotemporal Changes and Driving Factors of Cultural Relics on the Tibetan Plateau Since the Holocene

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Abstract

Based on ArcGIS spatial analysis, this study employs geostatistical methods including kernel density estimation, average nearest neighbor index, and global spatial autocorrelation to investigate the spatiotemporal evolution of 14,339 ancient cultural relics on the Tibetan Plateau since the Holocene and their influencing factors. The results show that the nearest neighbor index for each ancient cultural relic was less than 1, and the global Moran' s I value ranged between 0 and 1, indicating positive spatial autocorrelation and an agglomerated distribution pattern. The distribution core of ancient cultural relics transitioned from the plateau hinterland during the Paleolithic period to the southeastern marginal valleys during the Neolithic period, and subsequently to the eastern region after the Bronze Age. The morphological characteristics of the spatial distribution evolved through several distinct patterns: uniform distribution (Paleolithic), marginal valley type (Neolithic), valley agglomeration type (Bronze Age), degraded dispersion type (Tibetan regime tribe period), half-moon widespread type (Tubo Dynasty period), plaque type (Yuan Dynasty), and contiguous cluster type (Ming and Qing dynasties). The spatiotemporal distribution of ancient cultural relics on the Tibetan Plateau was jointly influenced by natural conditions including altitude, climate change, and vegetation dynamics, as well as human factors such as production modes, technological development, warfare, population migration, and political policies.

Keywords: Holocene; ancient cultural relic; spatiotemporal change; Tibetan Plateau

2.2 GIS and RS Methods

GIS and RS methods were applied to analyze the spatial patterns of ancient cultural relics on the Tibetan Plateau. Previous studies have demonstrated the effectiveness of GIS-based spatial analysis for archaeological site distribution [26-28]. ArcGIS 10.2 software was utilized to process 90 m resolution DEM data for kernel density analysis. The kernel density estimation method was employed to calculate the spatial concentration of cultural relics, with a search radius of 14 km applied to generate density surfaces. The average nearest neighbor index was calculated to assess the degree of clustering, where values less than 1 indicate significant aggregation. Spatial autocorrelation was measured using Moran' s I statistic to evaluate the global spatial clustering pattern across different temporal periods.

The kernel density function was implemented as follows:

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} K\left(\frac{d_i}{h}\right)$$

where $f(x,y)$ represents the estimated density at location (x,y), n is the number of points, h is the bandwidth (search radius), K is the kernel function, and d_i is the distance between the estimation location and point i. A quartic kernel function was applied with bandwidth selection based on the optimal smoothing parameter.

For spatial autocorrelation analysis, Moran' s I was calculated using the formula:

$$I = \frac{n}{S_0}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

where n is the number of observations, x_i and x_j are values at locations i and j, $\bar{x}$ is the mean, and W_{ij} is the spatial weight matrix. A rook contiguity weighting scheme was applied, where $W_{ij} = 1$ if locations i and j share a boundary and 0 otherwise.

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3 Results and Analysis

3.1 Temporal Distribution Patterns The spatial distribution of ancient cultural relics exhibited distinct temporal patterns corresponding to major archaeological periods. During the Paleolithic period, sites were uniformly distributed across the plateau hinterland. The Neolithic period saw concentration in southeastern marginal valleys, with kernel density values ranging from 0.00464 to 0.31091 sites per km². The Bronze Age featured valley agglomeration patterns with significantly higher densities. The Tibetan regime tribe period showed degraded dispersion, while the Tubo Dynasty period displayed a half-moon widespread distribution. The Yuan Dynasty exhibited plaque-type distribution, and the Ming and Qing dynasties showed contiguous cluster patterns.

The average nearest neighbor index values for all periods were significantly less than 1 (Table 1), with Z-scores exceeding -1.96, confirming statistically significant clustering at the 95% confidence level. The strongest clustering occurred during the Neolithic and Bronze Age periods, with indices of 0.087 and 0.199 respectively.

3.2 Spatial Autocorrelation Analysis Global Moran' s I values for all temporal periods ranged between 0 and 1 (Table 2), indicating positive spatial autocorrelation. The Z-scores exceeded 1.96 for all periods, confirming that the clustering patterns were statistically significant. Moran' s I values greater than 0 indicate spatial clustering, while values less than 0 would suggest dispersion. Approximately 67.07% of sites were located within 2,500 m elevation bands, showing strong correlation with topographic factors.

The spatial autocorrelation analysis revealed that the distribution of cultural relics was not random but exhibited clear spatial dependence. The highest Moran' s I values occurred during periods of stable political organization (Tubo Dynasty: 0.499) and intensive agricultural settlement (Ming and Qing: 0.335), suggesting that human social structures reinforced spatial clustering patterns.

3.3 Influencing Factors The spatiotemporal distribution of ancient cultural relics was influenced by both natural environmental factors and human activity variables. Altitude was a primary constraint, with 72.46% of all sites located below 4,000 m during the Neolithic and Bronze Age periods. Climate change, particularly precipitation variations recorded in lake sediments [32-38], directly affected human settlement patterns. Temperature fluctuations of 3-5°C during the Holocene [36] correlated with major shifts in site distribution.

Vegetation dynamics and water availability were critical factors, as evidenced by the concentration of sites in valley systems with annual precipitation exceeding 200 mm. The development of agricultural technology during the Bronze Age enabled settlement expansion into higher elevation zones previously unsuitable for sustained occupation.

Human factors including production mode transitions (from foraging to agriculture), technological innovations (particularly irrigation), warfare, population migration, and political policies (especially during the Tubo Dynasty and subsequent imperial periods) fundamentally reshaped the spatial organization of settlements. The establishment of administrative centers during the Yuan, Ming, and Qing dynasties created hierarchical settlement systems that are reflected in the contiguous cluster patterns observed in the spatial analysis.

[Figure 3: see original paper]

[Figure 4: see original paper]

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