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Spatio-temporal Differentiation of Urban Tourism Vitality in Lanzhou City Center

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Abstract

Against the backdrop of accelerating urbanization and the deepening integration of the experience economy, urban tourism vitality has become a crucial linkage between urban functions, cultural assets, and ecological systems. Taking the central urban area of Lanzhou—a quintessential valley-type city—as the study area, this research integrates Baidu population heatmap data, multi-dimensional geographical information, and socioeconomic statistics. By employing Kernel Density Estimation and Global and Local Moran's I indices, the study investigates the spatiotemporal differentiation patterns and driving mechanisms of tourism vitality across macro-scale human flow aggregation and intrinsic urban characteristics. The results indicate that: (1) Spatially, constrained by the "two mountains flanking one river" topography, tourism vitality exhibits a pronounced "core–periphery" polarization and a "ribbon-like and clustered" agglomeration pattern, with the riparian zones of Chengguan and Qilihe Districts forming a stable high-vitality core, while Anning and Xigu Districts constitute extensive low-vitality cold spots. (2) Temporally, tourism vitality demonstrates strong "day-type dependency": rest days follow a "mid-afternoon unimodal peak" pattern with the highest intensity; working days display a "trough–surge–plateau" trajectory locked by commuting rhythms and yield the lowest polarization; public holidays (Qingming Festival) exhibit a "broad-peak persistence" with peripheral hotspot diffusion driven by extended leisure time budgets. (3) The non-equilibrium evolution of tourism vitality is jointly shaped by valley-topography confinement, spatial allocation of tourism-commercial functions, and temporal constraints of human activities. These findings enhance the understanding of human–land relationships in valley-type cities and provide a scientific basis for optimizing tourism spatial planning and peak-period crowd management in nodal cities of Northwest China.

Keywords

Tourism vitality, Spatiotemporal differentiation, Baidu heatmap, Valley-type city, Lanzhou.

1. Introduction

In the context of accelerating global urbanization and deep integration of experience economy, urban tourism vitality has become a key element linking urban functions, culture, and ecological systems. Developing high-quality tourism is not only an important way to meet people's needs for a better life but also a strategic choice to promote consumption upgrading and regional coordinated development. National strategies such as the "Belt and Road" initiative and the ecological protection and high-quality development of the Yellow River Basin have put forward higher requirements for the tourism functions and attractiveness of node cities along the routes.

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Lanzhou, as the only provincial capital city traversed by the Yellow River, is an important transportation hub and cultural tourism city in Northwest China. Its central urban area presents a typical valley-belt spatial structure, and the geographical pattern of "two mountains enclosing one river" profoundly influences human flow aggregation, facility distribution, and tourism activities, making tourism vitality show significant heterogeneity in spatiotemporal dimension. Therefore, accurately identifying the spatiotemporal differentiation pattern of tourism vitality in Lanzhou's central urban area and deeply exploring its influencing mechanisms is not only a practical need to respond to national strategies and improve urban development quality but also provides an important theoretical reference for understanding the human-land relationship in valley-type cities.

Domestic and international scholars' research on urban tourism vitality mainly focuses on three dimensions: in terms of vitality measurement, research has shifted from traditional statistical data to big data applications such as mobile phone signaling and social media, with real-time population density data like Baidu heat maps providing new perspectives for studying human flow aggregation. Li et al. (2019) showed that urban population density exhibits different characteristics in different regions and time periods based on Baidu heat map data; Wang Lucang (2018) analyzed the spatiotemporal characteristics of population flow in Wuhan's central urban area using Baidu heat maps, finding that population aggregation shows obvious fluctuating changes, with stronger fluctuations on working days than on rest days. In terms of spatiotemporal differentiation patterns, research has shifted from static spatial distribution description to dynamic evolution analysis, using GIS spatial analysis, spatiotemporal clustering and other methods to reveal the fluctuation and agglomeration characteristics of urban tourism vitality. Mu et al. (2021) studied the spatiotemporal fluctuations of urban park spatial vitality through field observation and behavior mapping, finding significant differences in spatial vitality in time and space; Xie et al. (2021) studied the spatiotemporal differentiation of coupling coordination relationships among tourism-urbanization-ecological environment system in 35 major tourist cities in China, showing significant differences in tourism development models among different types of cities. In terms of driving mechanisms, research has expanded from focusing on material elements to including objective factors such as urban spatial structure and transportation accessibility, using spatial regression models, geographically weighted regression and other methods to reveal the influencing mechanisms of various factors on tourism vitality. Yang et al. (2023) showed that the spatial distribution of urban vitality in Chengdu displays a clustered and polycentric pattern, which can be attributed to urban spatial structure; Liu et al. (2019) found that POI density and entropy have strong correlations with urban vitality based on mobile phone data.

However, current research still has limitations: for cities under valley-type geographical constraints, the spatiotemporal differentiation patterns and driving mechanisms of their tourism vitality need to be further studied. This research integrates Baidu heat map and spatiotemporal statistical analysis methods, aiming to provide new theoretical perspectives and practical references for tourism vitality research in valley-type cities.

2. Research Area Overview and Data Sources

2.1. General characteristics of the study area

Located in central Gansu Province, the central urban area of Lanzhou functions as the political, economic, cultural, and tourism nucleus of the municipality. Characterized as a quintessential valley-type city, the built-up area extends linearly along the Yellow River valley, encompassing four administrative districts—Chengguan, Qilihe, Anning, and Xigu—with a total land area of approximately 1,500 km^2. The terrain maintains an average elevation of circa 1,520 meters and

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is classified under a temperate continental climate, marked by distinct seasonal variations and significant diurnal temperature ranges.

Serving as a pivotal spatial interface where Yellow River culture, Silk Road heritage, and modern urbanism converge, this district aggregates core tourism assets and reception infrastructure, including Zhongshan Bridge, Baita Mountain, the Yellow River Scenic Corridor, and the Gansu Provincial Museum. It constitutes the primary showcase for Lanzhou's urban tourism identity and the principal host zone for tourist activities. Furthermore, operating as a critical tourism distribution hub and integrated service nexus, the central urban area exerts a pronounced radiative and catalytic effect on regional tourism development across the entirety of Lanzhou Municipality.

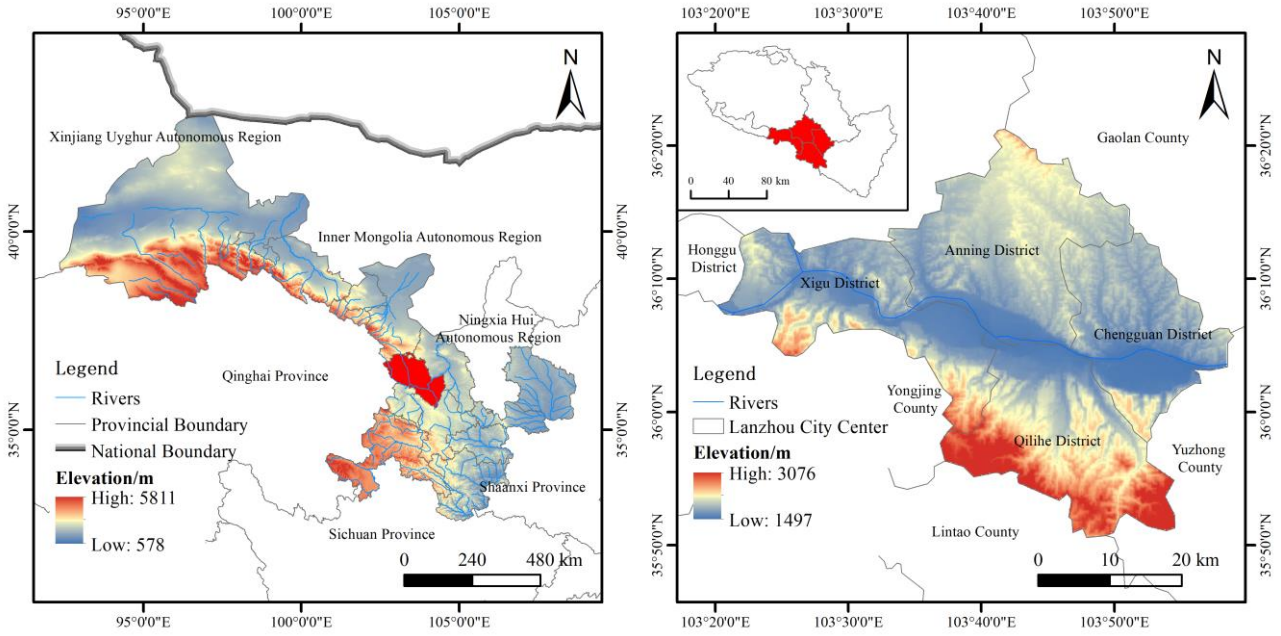

Fig 1 Overview of the Study Area

2.2. Data sources

This study employs multi-source data to analyze tourism vitality in the central urban area of Lanzhou, aiming to elucidate its formation mechanisms from two dimensions: macro-scale urban population aggregation and intrinsic urban characteristics. The datasets primarily comprise the following:

(1) Baidu Population Heatmap Data. These data serve as a robust proxy for quantifying the spatiotemporal intensity of human activities at the macro level. By invoking the API of the Baidu Maps Open Platform, we acquired population heatmap data for the central urban area across three temporal contexts: March 28, 2026 (a rest day), March 31, 2026 (a workday), and April 5, 2026 (Qingming Festival). This dataset captures population density at specific time nodes spanning weekdays, weekends, and statutory holidays. Subsequently, population aggregation intensity across various spatial units was quantified using heat values to delineate the temporal evolution patterns and spatial differentiation characteristics of tourism vitality.

(2) Multidimensional Geographical and Socioeconomic Data. To construct the system of explanatory variables for the driving mechanism analysis, this study systematically collected three categories of data: ① Basic Geographic Information Data: This encompasses road network distributions, public transit station layouts, and Point of Interest (POI) data, primarily utilized to measure facility density and service accessibility. ② Land Use and Planning Data: Sourced from official territorial spatial planning documentation of Lanzhou Municipality. ③ Socioeconomic Statistical Data: Including indicators such as permanent resident population and Gross Domestic Product (GDP) for each administrative district, obtained from the Lanzhou

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Statistical Yearbook. All spatial data were processed using ArcGIS version 10.8, with the geographic coordinate system unified to WGS_1984.

2.3. Methodology

2.3.1. Kernel Density Estimation

Kernel Density Estimation is a spatial statistical technique employed to transform discrete point data into a continuous density surface. The density value at any given location is derived from the cumulative contributions of all sample points within its vicinity, wherein proximal points exert a greater influence than distal ones. This method utilizes a kernel function to define the attenuation pattern of influence and employs a bandwidth parameter to regulate the smoothing scale. The output is a continuous raster surface that visually delineates the spatial clustering and dispersion patterns of point features. The mathematical formulation is expressed as follows:

$$f(x) = \frac{1}{mn^d}\sum_{i=1}^{m} K\left(\frac{x-x_i}{n}\right) \quad (1)$$

In the formula, $f(x)$ denotes the kernel density value of population flow within the study area, m represents the total number of sample points, n is the distance decay threshold, and d indicates the spatial dimension. K stands for the spatial weight function, while $x - x_i$ signifies the Euclidean distance from the estimation point x to the sample point x_i.

2.3.2. Global Moran's I Index

The Global Moran's I index is employed to evaluate whether tourism vitality exhibits statistically significant spatial clustering or dispersion trends across the entire study area. It quantifies the degree of spatial autocorrelation by comparing the attribute similarity of spatially proximate units against a random distribution. The mathematical formulation is specified as follows:

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

In the equation, w_{ij} denotes the spatial weight, and S_0 represents the sum of all spatial weights, serving as a normalization factor. n is the total number of spatial units; $(x_i - \bar{x})(x_j - \bar{x})$ measures the deviation of observed values for individual units from the global mean. A value of $I > 0$ indicates positive spatial autocorrelation (global clustering), $I < 0$ suggests negative spatial autocorrelation (dispersion), and $I = 0$ implies no significant spatial autocorrelation across the study area.

3. Spatiotemporal Differentiation Characteristics of Tourism Vitality in the Central Urban Area of Lanzhou

3.1. Temporal differentiation characteristics

Based on Baidu population heatmap data, the tourism vitality in the central urban area of Lanzhou on the rest day exhibited significant **spatiotemporal heterogeneity** and a high degree of **spatial agglomeration** (Fig. 2).

Spatially, the high-density core remained consistently anchored along the Yellow River corridor within Chengguan and Qilihe Districts throughout all time periods, manifesting a typical **"ribbon-like and clustered"** spatial agglomeration pattern. A stark density gradient existed between the core and peripheral areas (Anning and Xigu Districts), where the latter were characterized by sporadic, patchy distributions. Temporally, the 24-hour evolution followed a **unimodal pattern** defined by "**higher diurnal vitality and lower nocturnal vitality,**" culminating in an **afternoon polarization** effect. Vitality reached its nadir during the early morning hours (00:00–06:00). Starting at 09:00, spatial intensity converged rapidly upon the central axis and escalated, peaking at 15:00 with the highest kernel density of the day, marking

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the zenith of recreational activity. Although a gradual decline occurred between 18:00 and 21:00, the density remained elevated, indicating robust **nighttime economic vitality**.

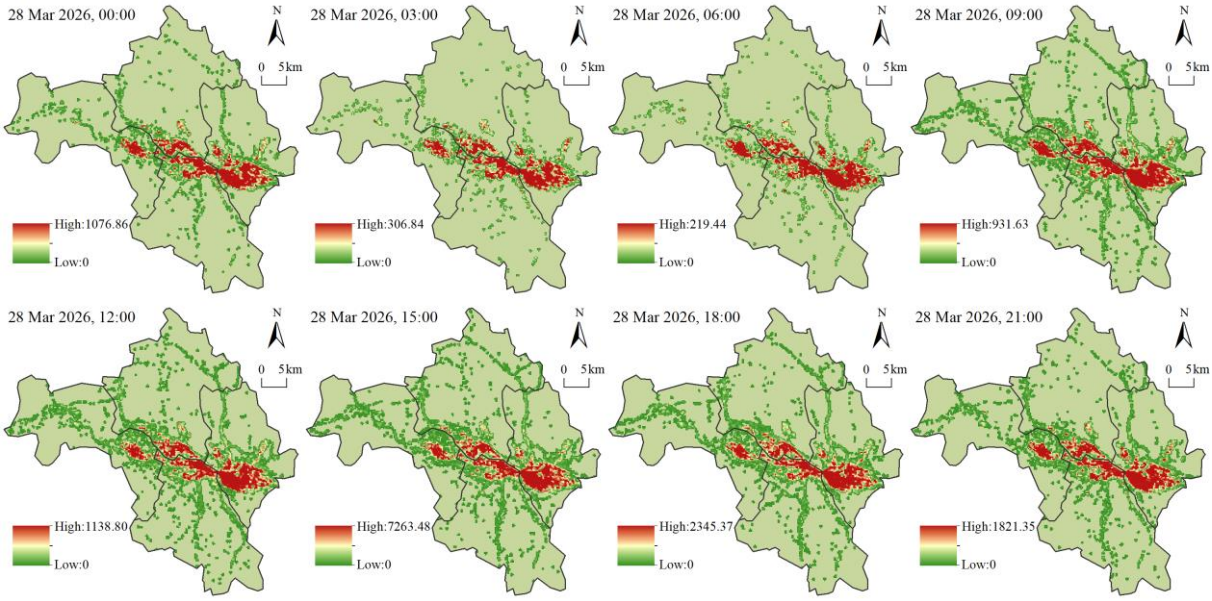

Fig.2 Kernel density distribution of 24-hour variations on rest days

Mechanistically, this spatiotemporal pattern is the joint product of **topographic constraints** and the **centripetal agglomeration** of tourism elements. Spatially, confined by the "two mountains flanking one river" valley topography, premium tourism resources (particularly dominant historical relics and architectural facilities) alongside commercial amenities are highly centralized in the old city center. This induces a pronounced **polarizing effect** on tourist and recreational flows toward the core. Temporally, the rest day afternoon constitutes an overlapping peak for out-of-town sightseeing and local leisure/shopping activities. Furthermore, the core area's well-developed nighttime lighting and dining-entertainment infrastructure effectively extended visitor dwell time, thereby sustaining a prolonged tail of nighttime vitality.

On the working day (March 31st), the spatiotemporal distribution of population vitality in the central urban area of Lanzhou continued to adhere to the constraints of the river valley's linear morphology. However, it exhibited significant deviations from the rest day in terms of agglomeration intensity and temporal rhythms (Fig. 3).

Spatially, the high-density core remained anchored in the central zones of Chengguan and Qilihe Districts. Nevertheless, compared to the rest day, the overall spatial agglomeration intensity on the working day was substantially diminished, accompanied by a marked contraction in the radiation scope of high-value areas. Temporally, rather than displaying the extreme afternoon polarization seen on holidays, the working day followed a "trough–surge–plateau" trajectory: vitality plunged to its daily nadir during the early morning (03:00–06:00), surged rapidly after 09:00, peaked at 12:00, and then maintained a relatively stable plateau with minor fluctuations until 18:00 before declining after 21:00.

This evolutionary pattern is primarily governed by the dual constraints of urban commuting routines and functional spatial structures. Temporally, workday travel is dominated by purpose-driven commuting flows, where discretionary leisure time is severely compressed. This shifts the vitality peak forward to the midday break (12:00) and results in a relatively homogenized heat distribution across daylight hours. Spatially, although the topography continues to channel populations along the Yellow River axis, the absence of large-scale recreational flows from local residents and tourists prevents the full activation of commercial

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and tourism amenities. Consequently, both the degree of spatial polarization and the overall scale of vitality on working days are markedly lower than those observed on rest days.

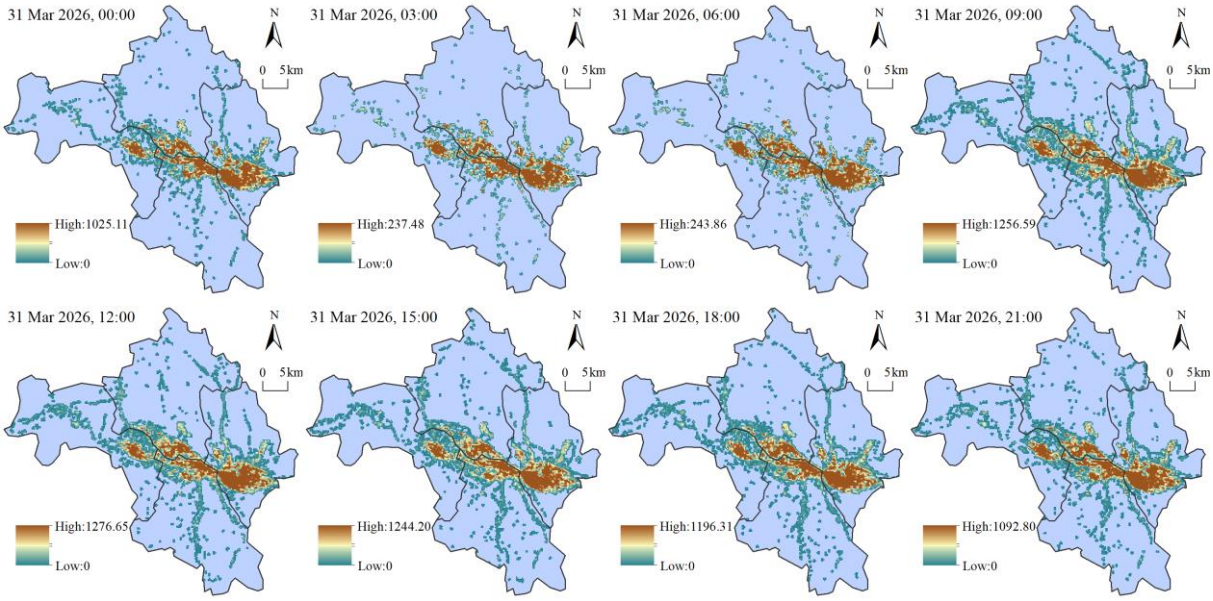

Fig.3 Kernel density distribution of 24-hour variations on workdays

During the holiday period (April 5th, Qingming Festival), the spatiotemporal evolution of population vitality in the central urban area of Lanzhou exhibited distinct characteristics of "core-periphery outward expansion" and a "broad-peak plateau" (Fig. 4).

Spatially, the vitality core remained concentrated along the Yellow River Valley (Chengguan and Qilihe Districts), maintaining a linear agglomeration pattern. However, compared to working days and ordinary rest days, there was a marked increase in patchy hotspots within the peripheral areas (e.g., the fringes of Anning and Xigu Districts), indicating a trend toward spatial diffusion. Temporally, diverging from the "homogeneous stability" of working days and the "afternoon unimodal peak" of ordinary rest days, the holiday exhibited a "broad-peak" evolution: vitality rose steadily from 09:00, reached a sustained high-density plateau between 15:00 and 18:00, and remained elevated even at 21:00. Notably, the overall agglomeration intensity peaked at a level intermediate between that of working days and ordinary rest days.

These characteristics result from the interplay between the unique attributes of the festival and the spatial distribution of tourism resources. The Qingming Festival, combining ancestral worship with "spring outing" traditions, prompted a substantial outflow of local residents to the suburbs, thereby suppressing the central urban area's peak agglomeration intensity compared to a typical weekend driven purely by commercial leisure. Mechanistically, the extended time budget afforded by the short holiday allowed tourists and residents to engage in a prolonged sequence of sightseeing, dining, and recreation from afternoon to evening. This elongated the temporal axis of high-frequency recreational activities, enabling the core area—anchored by its built environment and historical heritage—to sustain robust and enduring tourism vitality throughout the afternoon and into the night.

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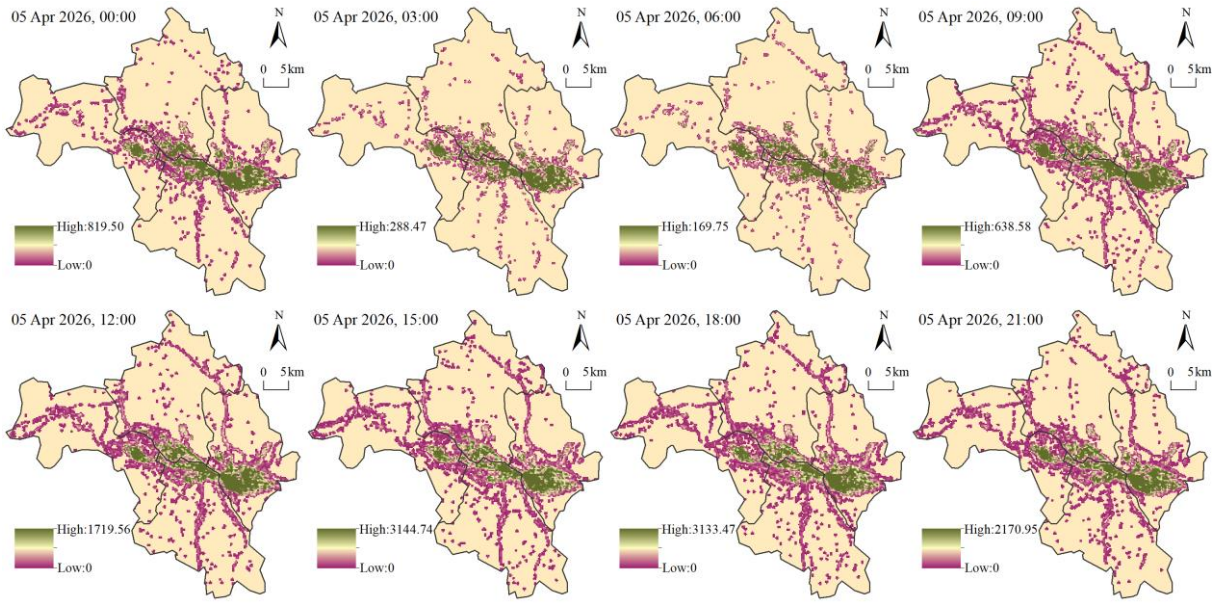

Fig.4 Kernel density distribution of 24-hour variations on public holidays

3.2. Spatial differentiation characteristics

This study constructed a regular grid system with a resolution of 1000 m × 1000 m and spatially joined the Baidu Huiyan population data to these grid units for aggregation. Based on this framework, a Local Indicators of Spatial Association (LISA) analysis was conducted to identify statistically significant clusters and spatial outliers within the study area.

As illustrated in Figure 5, the local spatial autocorrelation of population vitality in the central urban area of Lanzhou on the rest day (March 28th) exhibited a distinct "core-periphery" polarization pattern. Regarding the spatial distribution, High-High (H-H) clusters remained stable throughout the day along the core riparian zone at the junction of Chengguan and Qilihe Districts, forming a continuous belt of high vitality. Conversely, Low-Low (L-L) clusters were extensively distributed across the peripheral areas of Anning and Xigu Districts, as well as the urban fringe, representing prominent cold spots of activity. Low-High (L-H) clusters were primarily located surrounding the high-value core, exhibiting clear spatial transition attributes.

In terms of the temporal evolution sequence, the spatial extent of high-level hotspots contracted during the early morning hours (00:00–06:00). Starting at 09:00, coinciding with an increase in public recreational activities, the hotspot areas gradually expanded outward, reaching peak spatial connectivity and intensity between 12:00 and 15:00. Notably, a high degree of positive spatial correlation persisted even during the nighttime hours (18:00–21:00).

Constrained by the rigid topography of the Yellow River Valley, the highest-quality tourism resources and commercial amenities are highly concentrated in the old city center. This configuration exerts a strong spatial magnet effect on tourist and resident leisure flows, thereby shaping a stable high-vitality core. In contrast, the peripheral urban areas suffer from lower tourism resource abundance and are predominantly characterized by homogeneous residential or industrial land uses, lacking the dynamic mechanisms required to attract human activity; consequently, these areas have evolved into extensive low-vitality zones. Furthermore, the Low-High (L-H) transition zones immediately adjacent to the core reflect a profound "shadow of agglomeration" effect, wherein the dominant core siphons vitality from its immediate surroundings.

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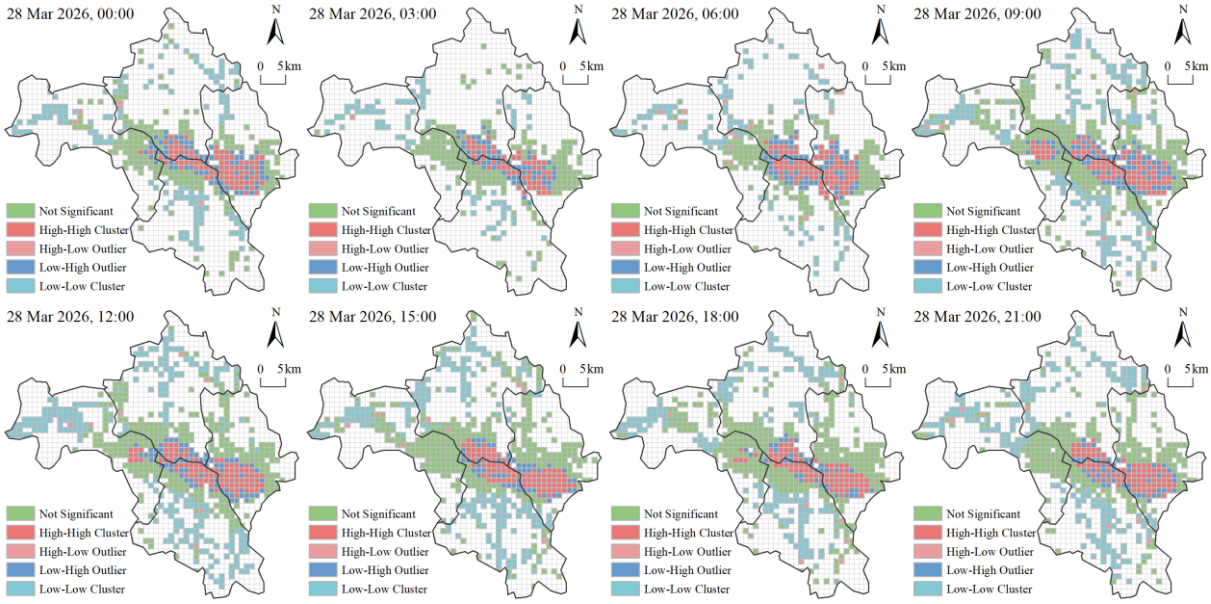

Fig.5 LISA cluster distribution of 24-hour variations on rest days

On the working day (March 31st), the local spatial autocorrelation of population vitality in the central urban area of Lanzhou similarly exhibited a “core-periphery” pattern of positive spatial correlation. However, compared to the rest day, the spatiotemporal evolution displayed more pronounced “rigid lock-in” and “tidal” characteristics (Fig. 6).

Focusing on the evolutionary trajectory of spatial agglomeration, High-High (H-H) clusters remained rigidly anchored in the central zone at the junction of Chengguan and Qilihe Districts, forming an extremely stable monocentric hotspot. Conversely, Low-Low (L-L) clusters were extensively distributed across the peripheral areas of Xigu and Anning Districts. Low-High (L-H) clusters acted as transition zones, tightly embedded along the outer edge of the high-value core.

Regarding the temporal succession, unlike the gradual expansion observed on the rest day, the high-value core on the working day consolidated rapidly during the morning rush hour (09:00) and maintained a highly stable, contiguous state throughout the core working period (09:00–18:00). Only a slight contraction of the boundaries was observed in the evening (21:00), indicating strong all-day resilience in the overall spatial structure.

The underlying mechanism lies in the monocentric agglomeration of high-quality jobs, administrative offices, and core commercial facilities in the old city center. This centripetal allocation generates a powerful “tidal” convergence force on the regular weekday commuting population, constructing an impregnable high-vitality core during daylight hours. The peripheral urban areas, dominated by homogeneous residential or traditional industrial functions, face a significant “population drainage” effect during working hours, lacking the necessary support for vitality and thus evolving into extensive cold spots. Consequently, this spatial mismatch between employment and residence ultimately shapes the distinct, highly entrenched spatial dependence characteristic of weekdays.

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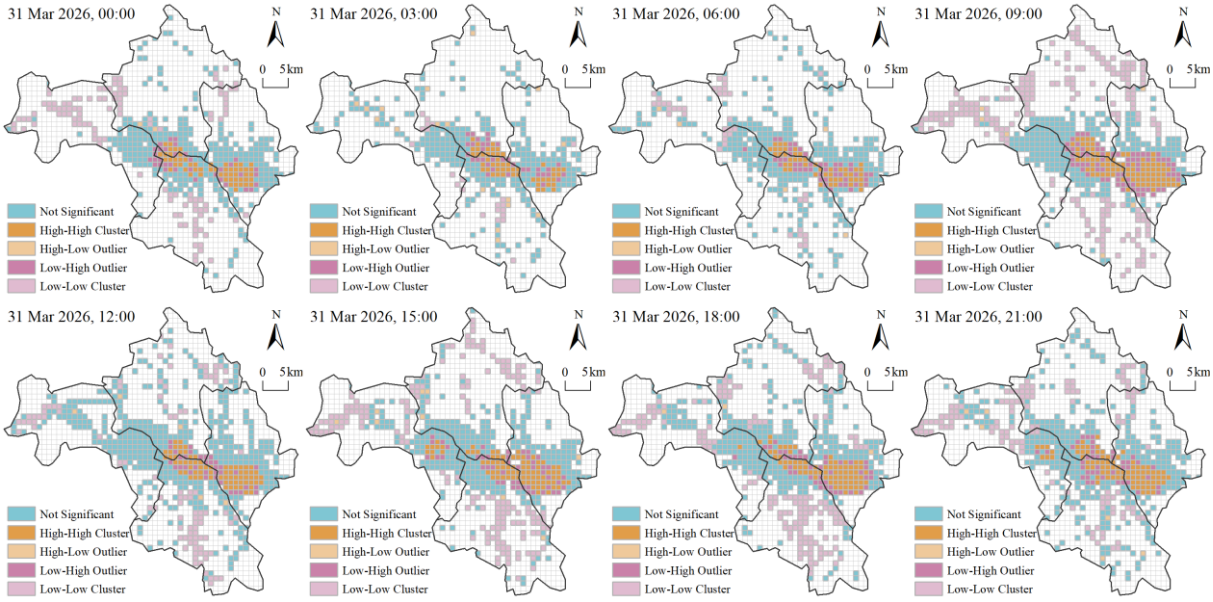

Fig.6 LISA cluster distribution of 24-hour variations on workdays

During the holiday period (April 5th, Qingming Festival), the local spatial autocorrelation of population vitality in the central urban area of Lanzhou exhibited an evolutionary trajectory that integrated both conventional structures and holiday-specific characteristics (Fig. 7).

In terms of spatial distribution, High-High (H-H) clusters predominated along the Yellow River in Chengguan and Qilihe Districts, establishing a relatively stable vitality hub. Conversely, Low-Low (L-L) clusters were scattered across the peripheral areas of Anning and Xigu Districts. Compared to the rigid spatial lock-in observed on working days, the polarization effect during the holiday was relatively mitigated. The peripheral low-vitality zones exhibited a tendency toward fragmentation, accompanied by a slight increase in the proportion of statistically insignificant areas.

Regarding the temporal succession, high-level aggregation in the central core emerged gradually after 09:00 and maintained a robust, contiguous scale from 12:00 to 21:00. Compared to ordinary rest days, this spatial stickiness of vitality proved more persistent throughout the afternoon and evening.

This phenomenon can be attributed to two mechanisms. First, guided by ritual activities such as tomb-sweeping and suburban excursions, a portion of the population dispersed toward non-core functional areas, resulting in an overall spatial de-intensification of agglomeration compared to workday commuting patterns. Second, the relative abundance of leisure time granted residents higher mobility freedom. This allowed the commercial, leisure, and cultural resources concentrated in the old city to exert a sustained attraction over extended periods, thereby supporting a relatively high-level, long-cycle pattern of positive spatial correlation within the central urban area.

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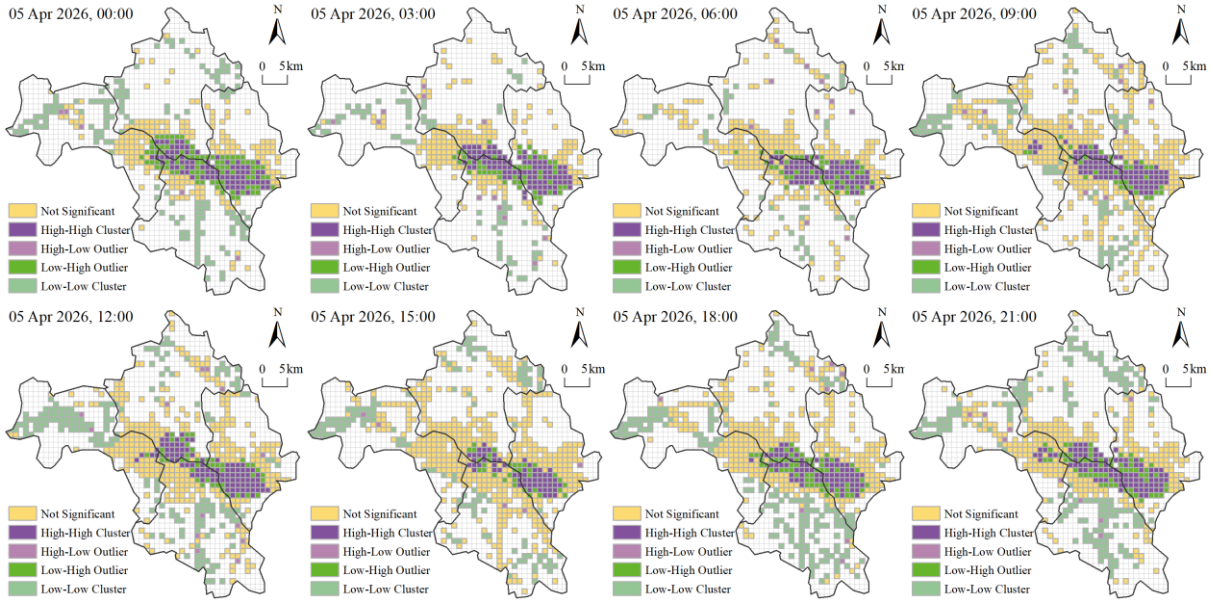

Fig.7 LISA cluster distribution of 24-hour variations on public holidays

4. Conclusion

Leveraging Baidu population heatmap data and high-resolution grid analysis, this study elucidates the complex spatiotemporal differentiation mechanisms governing tourism vitality in the central urban area of Lanzhou, shaped by the tripartite constraints of "valley topography, temporal rhythms, and functional space."

The findings reveal that the rigid topographic confinement of the "two mountains flanking one river" has induced a distinct "core-periphery" polarization and a "ribbon-like and clustered" agglomeration pattern. The riparian zones of Chengguan and Qilihe Districts, enriched with high-quality tourism resources and commercial amenities, function as stable high-vitality magnetic cores. Conversely, the peripheral urban areas, characterized by functional homogeneity and a scarcity of resources, have devolved into extensive low-vitality cold spots, profoundly influenced by the "shadow of agglomeration" effect.

Temporally, tourism vitality exhibits a strong "date-type dependency." Conventional rest days follow a "mid-afternoon unimodal" pattern, achieving the highest peak intensity due to the superposition of recreational flows and nighttime economic drivers. Working days, dictated by commuting logic, display a "trough-surge-plateau" rigidity, recording the lowest intensity and polarization due to the absence of leisure flow resonance. In contrast, the Qingming Festival holiday demonstrated a "broad-peak persistence" trait; while the peak intensity was moderated by population outflow for tomb-sweeping, the abundant time budget elongated the axis of high-frequency activities, resulting in the most sustained vitality from afternoon to night.

Further comparative analysis highlights significant disparities in spatiotemporal coupling. Working days and holidays represent two extremes: "commuting-oriented tidal locking" and "leisure-oriented outward diffusion." The former leads to "population drainage" and monocentric rigidity amid job-housing spatial mismatches, while the latter triggers peripheral expansion and the fragmentation of patchy hotspots driven by the dual attributes of tomb-sweeping and spring outings. In summary, tourism vitality in Lanzhou is a non-equilibrium product of topographic constraints, functional layouts, and time budgets. Its evolution not only validates the unique spatial differentiation laws of valley-type cities but also provides a scientific basis for optimizing public resource allocation and managing peak-period crowds.

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