

Spatial Differentiation Patterns and Driving Factors of Ski Resorts in China: A Multi-scale Perspective (Postprint)

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Abstract

From a multi-scale perspective spanning national, natural geographical division, and provincial levels, this study examines the spatial differentiation characteristics and driving factors of ski resorts in China, utilizing 899 ski resorts as the research subjects and comprehensively employing spatial analysis techniques including Voronoi coefficient of variation, kernel density, and Geodetector model. The results indicate: (1) The spatial distribution of ski resorts in China demonstrates a pattern of “dense in the north and sparse in the south, more in the east and fewer in the west,” with primary concentrations in North China, Northeast China, East China, and Northwest China. (2) At the national scale, the spatial agglomeration exhibits a “one core, three patches, and multiple surfaces” pattern, where high-density regions are mainly concentrated in Northeast China (Heilongjiang Province, Jilin Province), North China (Beijing, Hebei Province), and Northwest China (Xinjiang Uygur Autonomous Region, Shaanxi Province), while ski resorts in Central China, South China, and Southwest China are relatively sparse. (3) The driving factors of the spatial differentiation pattern are ranked as: natural environment > transportation capacity > socio-economic development > tourism development level, with significant interactions among all factors, predominantly manifesting as two-factor enhancement types, indicating that the spatial differentiation pattern is jointly influenced by multiple factors including natural environment and socio-economic conditions. Based on these findings, targeted recommendations are proposed, including fully leveraging spatial agglomeration advantages, formulating regionally differentiated development strategies, and strengthening infrastructure construction, to provide references for promoting the high-quality development of China’s ice and snow economy.

Full Text

Research on the Spatial Differentiation Pattern and Driving Factors of Chinese Ski Resorts from a Multi-scale Perspective

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Abstract

This study examines the spatial distribution patterns of 899 ski resorts across China from a multi-scale perspective, integrating national natural geographical zones and provincial regions. Using spatial analysis techniques including the Voronoi coefficient of variation, kernel density estimation, and geographic detector models, we investigated both the spatial differentiation characteristics and driving factors of Chinese ski resort distribution. Our analysis revealed three key findings: (1) Regional distribution pattern: China's ski resorts exhibit a distinct “dense in the north, sparse in the south, more in the east, less in the west” spatial configuration. The primary concentrations appear in north China, northeast China, east China, and northwest China. (2) Spatial agglomeration structure: A “one core, three areas, multiple facets” pattern emerges at the national scale. High-density areas are predominantly concentrated in northeast China (Heilongjiang and Jilin Provinces), north China (Beijing City, Hebei Province), and northwest China (Xinjiang Uygur Autonomous Region, Shaanxi Province). By contrast, central, south China, and southwest China show a sparse distribution of ski resorts. (3) Hierarchical driving factors: The determinants of ski resort spatial differentiation rank as follows: Natural environment > transport capacity > socio-economic development > tourism development level. Significant interaction exists among these factors, primarily through dual-factor enhancement mechanisms, demonstrating that both environmental and socio-economic variables jointly shape spatial distribution. Based on these findings, we recommend leveraging spatial agglomeration advantages, implementing regionally differentiated development strategies, and strengthening infrastructure to promote high-quality development of China's winter sports economy.

Keywords: multi-scale; ski field; spatial pattern; geographic detector; driving factors

1. Introduction

Under the boost of the “Winter Olympics effect,” the concept that “ice and snow are also invaluable assets” has charted a clear course for transforming ice and snow resource advantages into economic competitive advantages. According to the *China Ice and Snow Industry Development Research Report*,

the scale of China's ice and snow industry grew from 0.27×10^{12} yuan to 0.89×10^{12} yuan between 2015 and 2023, with projections reaching 1.5×10^{12} yuan by 2025. As crucial carriers of the ice and snow economy, ski resorts not only provide core venues for winter sports but also serve as preferred destinations for ice and snow tourism and cultural activities. The number of ski resorts in China increased by 6.74% year-over-year in 2023, establishing them as key engines driving industrial development and local economic growth. Consequently, exploring the spatial differentiation patterns of Chinese ski resorts is essential for rationally allocating ice and snow resources according to local conditions and fostering an integrated industrial chain encompassing winter sports, culture, equipment, and tourism.

Current research on ski resorts varies significantly between domestic and international contexts. International studies tend to integrate ski resorts into broader ski industry or ski tourism resort concepts, focusing primarily on two aspects: First, examining climate change impacts (shortened snow seasons, reduced snowfall) on the ski industry and corresponding adaptation measures. Second, analyzing the advantages and disadvantages of ski tourism resorts, constructing decision tree models for ski resort management strategies, and evaluating the impact of business intelligence applications on resort performance. Domestic research has traditionally approached China's ice and snow industry development from sports, economic, and management perspectives, analyzing current conditions, influencing factors, and development pathways. Under the influence of the digital economy era, scholars have explored how digital technologies empower ice and snow industry development, while others have investigated ski resort accessibility, market measurement, network attention, and spatial vitality evaluation from tourism perspectives.

With the rise of ice and snow tourism in recent years, the geographical sciences have increasingly focused on ski resort spatial patterns and their driving factors. However, existing research exhibits several limitations. First, in terms of scale, most geographical studies remain in their infancy, with limited literature examining ski resort patterns exclusively at the national scale or in individual provinces, neglecting scale effects on spatial distribution differences. More importantly, no studies have considered how China's different natural geographical zones influence the distribution of this resource-intensive industry. Second, while some studies have employed Analytic Hierarchy Process, structural equation modeling, and geographic detectors to analyze driving factors, they typically select individual indicators rather than constructing comprehensive indicator systems, and rarely incorporate tourism development levels as influential factors for emerging demand-driven ski resorts.

To address these gaps, this study utilizes 2023 data from 899 ski resorts across China, applying spatial statistics, kernel density analysis, and other methods to compare spatial differentiation patterns across national, seven natural geographical zones, and provincial scales. We construct a comprehensive evaluation index system for ski resorts and employ geographic detectors to analyze the im-

portance and interaction effects of driving factors. Our objective is to reveal the spatial differentiation patterns of Chinese ski resorts from a multi-scale perspective, providing a scientific foundation for coordinating regional ski resources, optimizing spatial allocation, and enhancing coordinated development of regional ice and snow tourism, thereby informing strategic and policy decisions for creating new growth poles in China's ice and snow tourism sector.

2. Methods

2.1 Data Sources This study employed web scraping via the Amap API to obtain geographic coordinates, names, and addresses of ski resorts across 31 provincial-level administrative regions (excluding Hong Kong, Macao, and Taiwan). After deduplication, cleaning, and verification against the official list published by the General Administration of Sport, we constructed a point vector database of 899 ski resorts, visualized using ArcGIS software. Data for influencing factors—including natural conditions, tourism development, socio-economic indicators, and transportation—were obtained from multiple sources: natural environment data from the Geospatial Data Cloud and the Chinese Academy of Sciences' Resource and Environmental Science Data Center; tourism development data from the Ministry of Culture and Tourism website; and socio-economic and transportation data from 2023 provincial statistical bulletins, statistical yearbooks, and the General Administration of Sport.

2.2 Methodology

2.2.1 Voronoi Polygon Coefficient of Variation The Voronoi polygon coefficient of variation measures spatial distribution uniformity. This method effectively validates nearest neighbor indices by calculating the coefficient of variation of Thiessen polygon areas, which vary according to random point set distributions. The formula is expressed as:

$$C_v = \frac{R}{\bar{S}} = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - \bar{S})^2}}{\frac{1}{n} \sum_{i=1}^n S_i}, \quad i = 1, 2, \dots, n$$

where R represents standard deviation, S_i denotes the area of the i th polygon, \bar{S} is the mean polygon area, n is the number of polygons, and C_v is the coefficient of variation. Scholars have established classification criteria: $C_v < 0.33$ indicates random distribution, $0.33 \leq C_v \leq 0.64$ indicates clustered distribution, and $C_v > 0.64$ indicates uniform distribution.

2.2.2 Kernel Density Analysis Kernel density estimation reveals the overall distribution pattern of discrete samples across continuous space. By calculating the density of ski resorts in adjacent regions, this method visually reflects spatial distribution patterns. The formula is typically expressed as:

$$f(S) = \frac{1}{nh} \sum_{i=1}^n k\left(\frac{S - S_i}{h}\right)$$

where h is the bandwidth determining the kernel function coverage, n is the total number of sample points, k is the spatial weight function, and S_i represents the distance from estimated point S to sample S_i . Kernel density results primarily depend on spatial weight, bandwidth, and weight function, with bandwidth being the most critical parameter.

2.2.3 Geographic Detector Geographic detectors comprise factor detection and interaction detection components. Factor detection identifies internal driving factors of spatial differentiation phenomena, while interaction detection analyzes comprehensive effects when multiple influencing factors interact. This method analyzes internal driving factors without excessive presuppositions and has been widely applied in social, economic, and natural science research. This study employs factor detection to examine influencing factors on the spatial distribution of 899 ski resorts and analyzes interaction effects among various factors.

3. Results

3.1 Spatial Distribution Characteristics

3.1.1 Overall Distribution Patterns To comprehensively understand ski resort spatial differentiation characteristics across scales, we analyzed spatial agglomeration and dispersion patterns, generating a spatial distribution map of Chinese ski resorts ([Figure 1: see original paper]). Based on China's seven natural geographical zones, we categorized ski resort distribution into east China, north China, central China, south China, southwest China, northwest China, and northeast China. Overall, China's ski resorts exhibit a "dense in the north, sparse in the south, more in the east, less in the west" pattern, concentrated primarily north of the Qinling-Huaihe line. Specifically, 31.85% of ski resorts are located in north China, 21.77% in northeast China, 16.50% in east China, and 15.27% in northwest China, while central China, south China, and southwest China account for only 7.26%, 5.62%, and 1.73% respectively. At the provincial scale, Hebei, Heilongjiang, Jilin, Shandong, Shanxi, Xinjiang, and Inner Mongolia exhibit the highest ski resort counts.

3.1.2 Spatial Agglomeration Degree Using the Voronoi polygon coefficient of variation method, we analyzed spatial agglomeration degrees at national and natural geographical zone scales (C_v). Results show that the national-level Voronoi polygon coefficient of variation is 633.74%, indicating clustered distribution across all scales. East China exhibits the highest agglomeration degree ($C_v = 1.89$), followed by north China ($C_v = 1.76$) and northeast China

($C_v = 1.68$). Central and south China show relatively lower coefficients (1.21 and 1.18 respectively), suggesting comparatively weaker agglomeration.

3.1.3 Spatial Distribution Density Kernel density analysis further reveals distribution patterns from multi-scale perspectives ([Figure 2: see original paper]). Nationally, ski resorts display a “one core, three areas, multiple facets” agglomeration pattern. The “one core” represents a high-density center radiating from Beijing and Hebei, while the “three areas” constitute secondary high-density zones centered in Heilongjiang-Jilin, Shandong, and Xinjiang-Shaanxi. At the natural geographical zone scale, northeast China’s ski resorts concentrate along the Harbin-Dalian and Suifenhe-Manzhouli railways and the Changbai Mountains, forming the densest distribution region. North China’s ski resorts cluster in the Beijing-Tianjin-Hebei area, significantly boosted by the Winter Olympics. Northwest China’s ski resorts concentrate in Xinjiang (particularly Urumqi, Changji, and Altay) and Shaanxi. East China’s ski resorts are mainly in Shandong and Jiangsu, while other regions show more dispersed distributions.

3.2 Driving Factors Analysis

3.2.1 Factor Selection Rationale Ski resorts, as important carriers of ice and snow activities, are shaped by comprehensive factors including natural environment and economic development. Natural factors—climate conditions and topography—are prerequisites for resource-based ski resorts, determining their grade, scale, and operating cycle. Socioeconomic factors, including regional tourism development levels, economic conditions, and transportation capacity, increasingly influence resort location and development as winter sports gain popularity. Based on previous research and comprehensive indicator system comparison, we selected 12 specific indicators across four dimensions: natural environment (elevation, slope, temperature, precipitation), tourism development level (total tourism revenue, total tourist arrivals, number of star-rated hotels), socio-economic development (per capita disposable income, proportion of tertiary industry added value), and transportation capacity (comprehensive highway density, railway network density, passenger turnover) ().

3.2.2 Geographic Detector Model Results **Single-factor detection results** () show that all 12 factors pass significance tests. The q-value ranking reveals: precipitation (X_4) > passenger turnover (X_{12}) > highway density (X_{10}) > temperature (X_3) > slope (X_2) > tourism revenue (X_5) > per capita disposable income (X_8) > star-rated hotels (X_7) > railway density (X_{11}) > tourist arrivals (X_6) > elevation (X_1) > tertiary industry proportion (X_9). Natural environment factors demonstrate the strongest influence, with precipitation, temperature, slope, and elevation all significantly affecting distribution. Ski resorts require specific geographic conditions: adequate precipitation/snowfall, low temperatures, and moderate slopes. The “Altai-Changbai” mountain ranges, located in the “golden latitude belt” for ski resorts, offer abundant snow resources and

long snow seasons, making Jilin and Xinjiang' s Altay region renowned winter sports destinations.

Tourism development factors, particularly star-rated hotels, significantly influence distribution by reflecting regional hospitality capacity. As essential elements of tourism (“eating, lodging, traveling, sightseeing, shopping, entertainment”), star-rated hotels accommodate visitor needs and interact synergistically with surrounding ski resorts.

Socioeconomic factors show substantial impact, with per capita disposable income being particularly influential. Income levels determine consumption capacity—higher incomes correlate with stronger participation willingness in skiing. Additionally, per capita GDP reflects regional economic foundations affecting infrastructure investment, while tertiary industry proportion influences service quality and attractiveness. Consequently, economically developed east China, despite less favorable natural conditions, hosts numerous ski resorts due to high consumption demand.

Transportation capacity factors—all three indicators—show significant effects. Passenger turnover reflects regional traffic intensity and transport capacity, while highway and railway density directly measure accessibility, influencing visitor travel choices and resort radiation ranges.

Interaction detection results () reveal that all factor pairs exhibit enhanced interactive effects greater than single-factor influences. Most interactions represent dual-factor enhancement types, with only slope-precipitation, temperature-precipitation, temperature-per capita income, and precipitation-per capita income showing non-linear enhancement. Notably, interactions between temperature (X_3) and elevation (X_1), slope (X_2) and temperature (X_3), temperature (X_3) and tourism revenue (X_5), and precipitation (X_4) and passenger turnover (X_{12}) produce particularly large q-values. This demonstrates that ski resort distribution results from complex interactions among natural environment, tourism development, socioeconomic conditions, and transportation capacity rather than single-factor causation. Suitable terrain and climate provide basic construction conditions, tourism development generates market demand, and service industry development enhances visitor experience, while high socioeconomic levels boost consumption capacity—all jointly promoting ski industry development.

4. Conclusions and Recommendations

4.1 Conclusions This study examined 899 ski resorts across national, natural geographical zone, and provincial scales using Voronoi polygon analysis, kernel density estimation, and geographic detector models. Three primary conclusions emerge:

First, spatial distribution exhibits a “dense in the north, sparse in the south, more in the east, less in the west” pattern concentrated north of the Qinling-Huaihe line. Nearly 85% of ski resorts are distributed in north China, northeast

China, east China, and northwest China, with sparse distribution in the Yangtze River' s southern regions.

Second, spatial agglomeration follows a “one core, three areas, multiple facets” pattern nationally. High-density zones concentrate in northeast China (Heilongjiang, Jilin), north China (Beijing, Hebei), and northwest China (Xinjiang, Shaanxi), while central, south, and southwest China show sparse distribution.

Third, driving factors rank as: natural environment > transportation capacity > socioeconomic development > tourism development level. All 12 factors demonstrate significant interactive enhancement effects, primarily through dual-factor enhancement mechanisms (with four non-linear enhancement exceptions). The spatial differentiation pattern results from complex interactions among natural, socioeconomic, and tourism factors rather than isolated influences.

4.2 Recommendations Based on these findings, we propose three policy recommendations:

Leverage spatial agglomeration advantages. Construct an ice and snow economy layout featuring “one region, two belts, multiple nodes” —establishing an internationally influential northern ice and snow economic leadership region centered on Inner Mongolia, Liaoning, Jilin, Heilongjiang, and Xinjiang; developing ice and snow Silk Road belts in Yanqing (Beijing), Chongli (Hebei), Yabuli (Heilongjiang), Changbai Mountains (Jilin), and Altay (Xinjiang); and creating demonstration zones that maximize agglomeration benefits.

Implement regionally differentiated development strategies. For the Beijing-Tianjin-Hebei region, leverage post-Winter Olympics momentum to develop comprehensive ski resorts centered on international winter sports events. For Xinjiang, Heilongjiang, and Jilin with abundant snow resources, upgrade infrastructure and service quality to enhance seasonal operational capacity. For economically advanced but naturally constrained regions like Shanghai, Jiangsu, and Zhejiang, accelerate indoor ski resort construction through technological innovation, implementing the “Northern Ice, Southern Expansion” strategy to promote balanced development.

Strengthen infrastructure construction. Since ski resort distribution is significantly influenced by transportation capacity and tourism development, implement an ice and snow “Grand Transportation” strategy by establishing integrated multi-modal transport networks (rail, road, air) to reduce travel time and distance. Develop distinctive public transport systems for ice and snow tourism, accelerate infrastructure improvements, expand hotel capacity in ice and snow scenic areas, and enhance overall operational and service capabilities.

Future research should further investigate how social factors like capital, policy, and market mechanisms influence ski resort distribution, and analyze micro-level enterprise data to explore evolution mechanisms from spatial agglomeration to industrial clustering.

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