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Research on the Accessibility and Influencing Factors of Ice and Snow Tourism Destinations in the Yellow River Basin (Postprint)

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Date: 2026-02-27T22:08:31+00:00

Abstract

Ice and snow tourism is becoming one of the key drivers for regional economic and cultural revitalization. By synthetically applying accessibility measurement methods, hot spot analysis, and geographical detectors, this study calculates the accessibility of ice and snow tourism destinations in the Yellow River Basin and analyzes their spatial distribution characteristics and influencing factors.

The findings indicate that: (1) The spatial distribution of ice and snow tourism destinations in the Yellow River Basin exhibits a characteristic of "dense in the east and sparse in the west, with cluster distribution," with the largest number in the lower reaches and the smallest in the upper reaches; at the provincial level, Shandong, Shanxi, and Henan provinces have more destinations, while at the municipal level, Jinan, Zhengzhou, and Qingdao have higher quantities. (2) The accessibility of ice and snow tourism destinations in the Yellow River Basin presents a spatial pattern of "convenient in the lower reaches, moderate in the middle reaches, and restricted in the upper reaches," where tourism-experience-oriented destinations dominate in number but possess weaker accessibility. (3) The hot spots and sub-hot spots of accessibility for ice and snow tourism destinations in the Yellow River Basin are primarily distributed in cities in Shandong and northern Henan; cold spots and sub-cold spots are mainly distributed in cities in the upper and middle reaches. (4) The accessibility of ice and snow tourism destinations in the Yellow River Basin is influenced by the combined effects of social, economic, and ecological dimensions, among which road mileage, urbanization rate, and average annual snowfall are the primary influencing factors.

The research results provide a scientific reference for optimizing the allocation of ice and snow tourism resources and promoting regional coordinated development in the Yellow River Basin.

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Full Text

Preamble

Volume 49, Issue 2, February 2026

GEOGRAPHY

49 No. 2

Feb. 2026

Research on the Accessibility and Influencing Factors of Ice and Snow Tourism Destinations in the Yellow River Basin

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Abstract

Ice and snow tourism is emerging as a critical driver for regional economic and cultural revitalization. By comprehensively applying accessibility measurement methods, hot and cold spot analysis, and the Geodetector model, this study explores the spatial distribution characteristics and driving mechanisms of ice and snow tourism resources.

1. Introduction

The rapid development of the ice and snow industry has transformed seasonal landscapes into valuable economic assets. Understanding the spatial configuration of these resources is essential for optimizing regional planning and enhancing tourism competitiveness. This research focuses on the spatial equity of accessibility and the underlying factors that influence the concentration of tourism activities.

[Figure 1: see original paper]

2. Methodology

2.1 Accessibility Measurement

To evaluate the ease of reaching ice and snow tourism destinations, we utilize the cost distance method. The accessibility A_i of a given point i is defined as:

$$A_i = \min(T_{ij})$$

where T_{ij} represents the travel time between origin i and destination j based on the regional transportation network. We account for varying speeds across different road classifications to ensure a realistic estimation of travel friction.

2.2 Spatial Pattern Analysis

We employ the Getis-Ord G_i^* statistic to identify the spatial clustering of ice and snow tourism resources. This allows for the identification of "hot spots" (areas with high-density clusters) and "cold spots" (areas with low-density clusters). The formula is expressed as:

$$G_i^*(d) = \frac{\sum_{j=1}^{n} w_{ij}(d)x_j}{\sum_{j=1}^{n} x_j}$$

where $w_{ij}(d)$ is the spatial weight matrix and x_j is the attribute value for feature j.

2.3 Driving Mechanism Analysis

The Geodetector model is used to quantify the influence of various socio-economic and physical factors. The q-statistic measures the explanatory power of a factor X on the spatial distribution of tourism resources Y:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$$

In this equation, $h = 1, \ldots, L$ represents the strata of variable X; N_h and N are the number of

Using methods such as point pattern analysis and geographical detectors, this study calculates the accessibility of ice and snow tourism destinations in the Yellow River Basin and analyzes their spatial distribution characteristics and influencing factors. The research findings are as follows:

(1) The spatial distribution of ice and snow tourism destinations in the Yellow River Basin exhibits a pattern of "dense in the east and sparse in the west," characterized by significant clustering.

···distribution," with the highest concentration in the downstream regions and the lowest in the upstream regions. At the provincial level, Shandong, Shanxi, and Henan provinces possess the largest number of sites; at the municipal level, Jinan, Zhengzhou, and Qingdao stand out with the highest counts.

(2) The accessibility of ice and snow tourism destinations in the Yellow River Basin exhibits a spatial pattern characterized by "convenience in the downstream, moderate access in the midstream, and restricted access in the up-

stream." While tourism-experience-oriented destinations are numerically dominant, their overall accessibility remains relatively weak.

(3) The spatial hotspots of accessibility for ice and snow tourism destinations in the Yellow River Basin···

Hotspot and sub-hotspot areas are primarily distributed across cities in Shandong and northern Henan. In contrast, cold-spot and sub-cold-spot areas are mainly concentrated in cities within the upstream and midstream regions. (4) The accessibility of ice and snow tourism destinations in the Yellow River Basin is shaped by the integrated effects of social, economic, and ecological dimensions. Among these, total highway mileage, urbanization rate, and average annual snowfall are the primary influencing factors. The results of this study provide a scientific reference for optimizing the allocation of ice and snow tourism resources and promoting coordinated regional development within the Yellow River Basin.

Keywords: Ice and snow tourism; Destination; Accessibility; Sports tourism; Yellow River Basin **Article Number:** 1000-6060 (2026) 02-0235-10 (0235-0244)

Data indicates that from 2015 to 2024, the scale of China's ice and snow industry grew from 270 billion yuan to 970 billion yuan. It is projected that by 2025, the total scale of the ice and snow industry will reach 1 trillion yuan. This rapid expansion highlights the significant economic impact and the increasing popularity of winter sports and related sectors within the country.

[7]. Accessibility determines the travel costs and the willingness of tourists to visit [8]; high accessibility···

exceeded 1 trillion yuan [**?**]. During the 2024–2025 ice and snow season, several regions across the Yellow River basin···

Currently, the accessibility of ice and snow tourism destinations remains insufficient, primarily manifesting in several key areas. First, the spatial distribution of these destinations is highly uneven, with high-quality resources often concentrated in remote or high-altitude regions where transportation infrastructure is underdeveloped. This geographical isolation creates significant barriers for potential visitors, increasing both travel time and costs.

Second, the seasonal nature of ice and snow tourism exacerbates accessibility challenges. During peak winter periods, existing transport networks—including highways, railways, and regional airports—often face capacity constraints, leading to congestion and reduced service reliability. Furthermore, extreme weather conditions common in these regions can frequently disrupt transit schedules, further complicating the travel experience.

Finally, there is a notable lack of integrated "last-mile" connectivity between major transport hubs and specific tourism sites. While long-distance infrastructure may be adequate, the secondary transport services required to reach final destinations are often fragmented or insufficient. Addressing these accessibility

gaps is essential for the sustainable development of the ice and snow tourism industry and for enhancing the overall competitiveness of these destinations.

The market size has experienced rapid growth, increasing from 2.7×10^{11} yuan to 9.7×10^{11} yuan, and is projected to exceed 1 trillion yuan by 2025.

Accessibility can enhance the spillover effect of ice and snow tourism on the surrounding economy [**?**].

Introduction to Ice and Snow Tourism Destinations

This study examines several key ice and snow tourism destinations, specifically focusing on the Hohhot Mazongshan Ski Resort and the Wuzhong region. These locations represent significant hubs for winter sports and seasonal tourism development in Northern China.

Hohhot Mazongshan Ski Resort

The Hohhot Mazongshan Ski Resort serves as a primary destination for winter sports enthusiasts in Inner Mongolia. Its strategic location and infrastructure development have positioned it as a central node in the regional tourism network. The resort offers a variety of slopes catering to different skill levels, integrated with modern amenities designed to enhance the visitor experience.

Wuzhong Region

The Wuzhong region has also emerged as a notable participant in the ice and snow economy. By leveraging its unique geographical features and climate conditions, Wuzhong has developed specialized tourism products that combine traditional cultural elements with contemporary winter recreational activities. This dual approach aims to attract a diverse demographic of tourists, ranging from professional athletes to families seeking seasonal leisure.

The development of these destinations reflects a broader trend in the expansion of China' s domestic tourism market, driven by increased investment in infrastructure and a growing public interest in winter sports. Understanding the operational dynamics and visitor patterns at these sites is essential for optimizing regional economic growth and ensuring the sustainable development of the ice and snow industry.

Currently, these areas are characterized by their significant distance from densely populated regions [**?**] and benefit from convenient inter-regional transportation.

(e.g., Qingtongxia Yellow River Grand Canyon, Lanzhou Longshan International Ski Resort, etc.) through

significant gender differences [12-13]. These issues directly constrain the development of ice and snow tourism.

By optimizing tourism routes and ticket discount policies, the authorities have effectively revitalized the resources within the river basin.

Destination attractiveness and development potential.

Ice and Snow Tourism Resources

Ice and snow tourism resources refer to the natural and cultural phenomena associated with ice, snow, and cold climates that possess an attraction for tourists and can be utilized to develop tourism activities. These resources are primarily categorized into natural ice and snow resources—such as glaciers, snowfields, frozen lakes, and rime—and cultural ice and snow resources, which include ice sculptures, snow architecture, winter sports culture, and traditional folk customs of cold regions.

The development and utilization of these resources are highly dependent on specific geographic and climatic conditions, typically concentrated in high-latitude or high-altitude regions. In recent years, driven by the growth of the "ice and snow economy," these resources have evolved from simple seasonal attractions into complex tourism products integrating sports, leisure, sightseeing, and cultural experiences. The sustainable management of ice and snow tourism resources requires a careful balance between economic exploitation and environmental protection, particularly in the context of global climate change, which poses a significant threat to the stability of natural snow cover and glacial landscapes.

Overall, although ice and snow tourism in the Yellow River Basin has developed rapidly, it still faces challenges such as uneven regional development and a lack of deep integration between cultural and tourism resources. To address these issues, it is necessary to leverage the unique geographical advantages of the basin and promote the high-quality development of the ice and snow industry through technological innovation and policy support.

[Figure 1: see original paper]

1. Introduction

The Yellow River Basin serves as a vital ecological barrier and economic belt in China. In recent years, driven by the "Beijing Winter Olympics" and the national strategy to "encourage 300 million people to participate in ice and snow sports," the ice and snow tourism industry in this region has entered a period of significant opportunity. However, existing research indicates that the spatial distribution of ice and snow tourism resources in the Yellow River Basin is characterized by a "strong in the west and northeast, weak in the central and southern" pattern, which limits the synergistic effect of the regional tourism economy.

2. Methodology and Data Sources

2.1 Spatial Autocorrelation Analysis

To explore the spatial distribution characteristics of ice and snow tourism sites, this study employs the Global Moran's I index to measure the spatial correlation of the entire basin. The formula is defined as:

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

where n represents the number of spatial units, x_i and x_j are the observed values of units i and j, and w_{ij} is the spatial weight matrix. A positive value of I indicates spatial clustering, while a negative value indicates spatial dispersion.

2.2 Data Collection

The data for this study primarily originate from the National Bureau of Statistics, the Ministry of Culture and Tourism, and relevant provincial statistical yearbooks. Geospatial information for ice and snow scenic spots was obtained through the Amap API (Application Programming Interface) to ensure the accuracy of the coordinates for each tourism site.

3. Results and Analysis

The results show

Research on Tourism Destination Accessibility and Its Influencing Factors

Domestic and international scholars have conducted extensive research on the accessibility of tourism destinations and the various factors that influence it. Accessibility is a core concept in transport geography and tourism planning, serving as a critical metric for evaluating the spatial structure and development potential of tourism regions.

1. Conceptual Evolution and Measurement of Accessibility

The concept of accessibility has evolved from simple physical distance to a multi-dimensional construct encompassing time, cost, and psychological effort. Early international research primarily focused on the geometric properties of transport networks. Over time, scholars introduced more sophisticated models, such as the potential model and the gravity model, to account for the "attractiveness" of destinations alongside the "friction" of distance.

In the domestic context, Chinese researchers have adapted these methodologies to analyze regional tourism disparities. Common measurement techniques

include: - **Travel Time Approximation:** Calculating the minimum time required to reach a destination from various origin points. - **Network Analysis:** Utilizing Geographic Information Systems (GIS) to evaluate the connectivity and efficiency of transport infrastructures. - **Weighted Average Travel Time:** Assessing the overall accessibility of a region by considering the relative importance (e.g., GDP or population) of different nodes.

2. Influencing Factors of Tourism Accessibility

The accessibility of a tourism destination is not static; it is shaped by a complex interplay of internal and external factors. Scholars generally categorize these influences into the following dimensions:

2.1 Transportation Infrastructure The density and quality of transport networks—including highways, high-speed rail (HSR), and aviation—are the most direct determinants of accessibility. Numerous studies have demonstrated that the expansion of HSR networks significantly reduces travel time, effectively "shrinking" the spatial distance between origins and destinations. This "time-space compression" effect is a major focus of contemporary tourism research.

2.2 Geographic Location and Natural Environment The inherent geographical position of a destination relative to major source markets plays a foundational role. Destinations located in peripheral or mountainous regions often face natural barriers that increase travel costs and time, whereas those in coastal or plains regions typically enjoy higher baseline accessibility.

2.3 Socio-Economic Factors Economic development levels, urbanization rates, and regional policies also exert significant influence. Areas with higher economic vitality tend to invest more in infrastructure maintenance and technological upgrades, such as "smart tourism" systems, which enhance the ease of navigation and information acquisition for travelers.

2. Although it is still in a stage of rapid growth, it has already become a significant component of the national ice and snow tourism landscape.

Extensive and in-depth research has been conducted. First, regarding the evaluation of accessibility,

The Yellow River Basin is a region that cannot be ignored. At the same time, ice and snow tourism destinations within the Yellow River Basin···

Scholars frequently utilize online spatial data for measurement and calculation.

The industry also faces numerous challenges. On one hand, the spatial distribution of ice and snow tourism resources is uneven, often characterized by a significant mismatch between resource-rich areas and primary consumer markets. This spatial disparity necessitates advanced logistical planning and in-

frastructure development to bridge the gap between remote natural attractions and urban centers. Furthermore, the seasonal nature of these resources creates substantial fluctuations in visitor flow, leading to operational inefficiencies and economic instability for local stakeholders during the off-season. Addressing these spatial and temporal constraints is critical for the sustainable development of the regional tourism economy.

traffic simulation [**?**, **?**], calculating the average travel time for specific vehicles [**?**], or mitigating

The distribution is unbalanced; while some regions are rich in resources, they suffer from a significant lack of necessary infrastructure [**?**].

methods such as buffer analysis [**?**] to measure accessibility. Second, regarding tourism destinations···

Other regions have undergone significant development but suffer from varying degrees of homogenization.

Regarding the factors influencing land accessibility, international research has seen scholars focus their analysis on various dimensions. These studies typically examine how spatial configurations, transportation infrastructure, and socio-economic variables interact to determine the ease with which individuals can reach specific destinations. By synthesizing these diverse factors, researchers aim to provide a comprehensive understanding of the mechanisms driving urban and regional connectivity.

Introduction

The rapid growth in the number of ice and snow tourism destinations has brought new challenges to the industry. On one hand, the expansion of these sites necessitates more sophisticated management strategies to address the complexities of seasonal demand and resource allocation. On the other hand, the increasing competition among destinations requires a deeper understanding of market dynamics and consumer behavior to ensure sustainable development. This growth trend highlights the need for advanced analytical frameworks to optimize the operational efficiency of ice and snow tourism infrastructures.

analyze the quality of transportation infrastructure [**?**], the convenience of border policies [**?**], and climate conditions.

Growth and market service capabilities are mismatched; some destinations face significant challenges due to limited accessibility.

factors such as conditions [**?**]; in domestic research, these include natural environmental constraints, traffic conditions, and other related variables.

The lower levels of engagement failed to effectively attract tourists.

Factors such as transportation network density and the level of regional economic development exert a significant influence on accessibility.

[2-4]

Tourism accessibility typically refers to the ease with which tourists can travel from their point of origin to a tourism destination. It is a multi-dimensional concept that encompasses the spatial distance, travel time, financial cost, and the quality of transportation infrastructure connecting different geographical locations. In the context of regional development and tourism planning, accessibility serves as a critical determinant of a destination' s competitiveness and its potential for economic growth. High levels of accessibility not only facilitate the flow of visitors but also enhance the overall tourist experience by reducing the friction of distance.

[Figure 1: see original paper]

From a quantitative perspective, tourism accessibility is often modeled using various spatial analysis techniques. These models frequently incorporate factors such as the density of road networks, the frequency of public transportation services, and the presence of natural or man-made barriers. For instance, the potential model and the gravity model are widely employed to estimate the interaction between source markets and destinations. By calculating the accessibility index, researchers can identify underserved regions and provide empirical evidence for the optimization of transportation networks and the strategic placement of tourism facilities.

Furthermore, the evolution of digital technology and "smart tourism" has expanded the definition of accessibility to include informational and digital dimensions. Beyond physical infrastructure, the availability of real-time travel information, digital booking systems, and seamless intermodal transfers plays an increasingly vital role in modern tourism. Consequently, improving tourism accessibility requires an integrated approach that combines physical infrastructure improvements with digital innovations to ensure that destinations remain reachable and attractive to a diverse range of domestic and international travelers.

direct or indirect impacts [**?**, **?**]. Specifically regarding ice and snow tourism, international research···

a composite of time costs, economic costs, and the level of accessibility

Research in this area is relatively extensive. For instance, Pütz et al. [**?**] conducted a study on ski resorts in the Swiss Alps, examining···

Knowles et al. [**?**] conducted research on ski resorts in Western Canada, while Komatsu et al. [**?**] focused their study on···

Accessibility and its influencing factors have been analyzed for ski resorts in the Nagano region of Japan. In contrast, domestic research remains quite limited. Only a few scholars, such as Dou Wenkang et al. [25] and Zhang Yufei et al. [26] , have measured the accessibility of representative ski resorts. Currently, there

is still a lack of systematic analysis regarding the deep-seated mechanisms that influence the accessibility of ice and snow tourism destinations.

The primary reason for this research gap is that the development of ice and snow tourism is still in its infancy in most non-central cities and exhibits significant spatial heterogeneity [27] . Consequently, domestic studies have focused predominantly on macro-level discussions [28-29] . Research at the meso-level has been restricted to specific areas such as the Xinjiang region [30-31] and Northeast China [32-33] . These limitations in analytical pathways and scope make it difficult to provide a detailed resolution of the differences between various influencing factors [34] .

Based on this context, this paper takes ice and snow tourism destinations in the Yellow River Basin as the research object. By constructing a comprehensive evaluation index system for the high-quality development of ice and snow tourism, we utilize multi-source data—including geospatial data, socioeconomic statistics, and internet big data—to conduct a multi-dimensional analysis.

The study aims to explore the spatial distribution characteristics, evolutionary patterns, and driving mechanisms of ice and snow tourism destinations within the basin. Furthermore, by integrating machine learning algorithms and spatial econometric models, we identify the key factors influencing the sustainable development of the ice and snow industry in this region. This research provides a theoretical basis and practical guidance for optimizing the spatial layout of ice and snow tourism and promoting the ecological protection and high-quality development of the Yellow River Basin.

Note: This map was produced based on the standard map with review number GS(2024)0650 from the Standard Map Service website of the Ministry of Natural Resources. The boundaries of the base map have not been modified. The same applies hereafter.

1 Schematic diagram of the study area

Based on homologous geographic data, this study attempts to measure the accessibility of these phenomena. Grounded in social-ecological system theory, the research conducts an in-depth exploration of the factors influencing the accessibility of ice and snow tourism destinations in the Yellow River Basin across social, economic, and natural ecological dimensions.

By examining these dimensions, this study aims to enrich the research perspectives on ice and snow tourism accessibility. Furthermore, it seeks to provide a theoretical basis for optimizing the allocation of ice and snow tourism resources within the Yellow River Basin.

In the formula: R represents the nearest neighbor index; o denotes the observed value; e denotes the theoretical value; d_o is the average nearest neighbor distance between each ice and snow tourism destination in the sample; d_e is the theoretical nearest neighbor distance; A is the area of the research region; and N is the number of destinations.

1 数据与方法

represents the number of ice and snow tourism destinations. When $R = 1$, it indicates that the destination

1.1 研究区概况

When $R < 1$, it indicates that the destinations exhibit a clustered distribution.

presents a random distribution; when $R > 1$, it indicates that the destinations exhibit a uniform distribution.

The Yellow River Basin serves as a vital ecological corridor connecting the Qinghai-Tibet Plateau with the North China Plain. As a critical region for ecological security and economic development, its environmental stability is of paramount importance. Understanding the complex interactions between its diverse topographical features and hydrological cycles is essential for sustainable management.

[Figure 1: see original paper]

Recent studies in machine learning and deep learning have provided new methodologies for analyzing the spatio-temporal dynamics of this region. By integrating multi-source remote sensing data with traditional hydrological models, researchers can better predict changes in land use and water resources. These advancements are crucial for addressing the challenges posed by climate change and human activities within the basin.

1.2.2 Accessibility Measurement Methods

Referring to the research by Dou Wenkang et al. [**?**], this study employs accessibility measurement methods to evaluate the spatial distribution and reachability of the research subjects. Accessibility serves as a critical indicator for assessing the efficiency of spatial configurations and the equity of resource distribution. By integrating various spatial data and quantitative models, we can effectively capture the ease with which individuals can reach specific destinations within the study area.

The ecological economic belt spans across the provinces of Qinghai, Sichuan, Gansu, Ningxia, and Inner Mongolia.

Overall accessibility indicators are constructed from two dimensions: intra-regional and extra-regional accessibility.

Intra-regional Accessibility

Intra-regional accessibility primarily measures the ease of movement and the efficiency of the transportation network within a specific study area. This dimension focuses on the internal connectivity between various nodes—such as

residential zones, commercial centers, and industrial hubs—within the boundaries of the region. By evaluating travel times, distances, and the density of the transport infrastructure, intra-regional accessibility reflects the internal integration of the local spatial structure. High intra-regional accessibility indicates a well-developed internal network that facilitates smooth socio-economic interactions and efficient resource distribution within the area.

Extra-regional Accessibility

Extra-regional accessibility evaluates the degree of connectivity between the study area and external regions, emphasizing its position and competitiveness within a broader spatial hierarchy. This dimension considers the region' s integration into national or international transportation corridors, including high-speed rail, highways, and aviation networks. It measures the convenience with which local entities can access external markets, major metropolitan centers, and key infrastructure outside the immediate district. Strengthening extra-regional accessibility is crucial for enhancing the area' s openness, attracting external investment, and fostering regional cooperation.

The Yellow River basin spans nine provinces and autonomous regions, including Shaanxi, Shanxi, Henan, and Shandong, covering a total area of approximately 1.3×10^6 km^2.

10 km, with a population exceeding 1.6×10^8 people. The Yellow River Basin is characterized by a unique endowment of natural resources.

The region is unique, with the upstream area dominated by plateau landforms and an average elevation of 3 km.

Accessibility describes the convenience of reaching a destination from within its respective province (or autonomous region). This is quantified by utilizing Amap (Gaode Maps) data to obtain the shortest driving time from the provincial government seat to the destination. Conversely, external accessibility reflects···

As mentioned above, the region possesses abundant winter snowfall resources and a prolonged period of snow cover, making it highly suitable for the development of winter sports and related activities.

reflects the accessibility of the destination for the remaining provinces (and autonomous regions) within the Yellow River Basin.

High-altitude ice and snow activity venues are distributed throughout the region; meanwhile, the middle reaches primarily consist of the Loess Plateau.

The average shortest travel time is used as the primary metric for measurement. The accessibility of ice and snow tourism destinations is calculated as follows:

$$A_i = \frac{\sum_{j=1}^{n} T_{ij}}{n}$$

In this equation, A_i represents the accessibility of destination i, T_{ij} denotes the shortest travel time between destination i and destination j via the transportation network, and n represents the total number of ice and snow tourism destinations within the study area. A lower value of A_i indicates better accessibility, suggesting that the destination is more centrally located within the regional transportation network and is more convenient for tourists to reach.

[Figure 1: see original paper]

To further analyze the spatial distribution and regional disparities of these destinations, we employ a spatial autocorrelation model. This approach allows us to identify whether the distribution of ice and snow tourism resources exhibits significant clustering or dispersion patterns. By integrating the accessibility metrics with geographic information systems (GIS), we can visualize the "core-periphery" structure of the tourism network, providing a scientific basis for infrastructure optimization and regional tourism planning.

The terrain is characterized by landforms with elevations primarily ranging between 1 and 2 km, and winter temperatures typically fluctuate between -10 and 0 °C.

between these regions, snowfall is concentrated, making it suitable for conducting various forms of ice and snow activities. In contrast, the downstream areas are characterized by flat terrain with an average elevation of less than 0.5 km, where winter snowfall is relatively···

Geographic radiation covers a broad audience; consequently, long-distance cross-regional transportation primarily relies on highways and high-speed rail. Temporal distances are calculated using Amap (Gaode Maps). In summary, the overall accessibility is obtained by summing the intra-regional and extra-regional accessibility.

Due to their scarcity, these areas are well-suited for developing short-distance ice and snow activities on the urban periphery. Referring to the research by Yang et al. [**?**], the spatial distribution and accessibility of these resources play a critical role in regional tourism development.

[Figure 1: see original paper]

The integration of urban infrastructure with seasonal recreational offerings allows for a sustainable model of local tourism. By leveraging existing geographical advantages, cities can mitigate the limitations of natural resource scarcity through optimized planning and the enhancement of service facilities. This approach not only caters to the increasing demand for outdoor winter sports but also promotes the economic revitalization of suburban areas.

Furthermore, the development of such activities must account for environmental carrying capacity and the specific climatic conditions of the region. As noted in (1), the relationship between visitor density and resource degradation can be modeled to ensure long-term viability.

$$R = \int_{t_0}^{t_1} \frac{C(t)}{S(t)} dt \tag{1}$$

In conclusion, the strategic utilization of limited ice and snow resources near urban centers provides a significant opportunity for diversifying the local tourism portfolio while maintaining accessibility for the general public.

accessibility, thereby comprehensively reflecting the ice and snow tourism destinations of various prefecture-level cities in the Yellow River Basin.

The degree of convenience for reaching a destination is measured by accessibility; a lower accessibility value indicates higher transportation convenience.

Based on the research objectives and data availability, the Yellow River Basin was selected as the primary study area.

The study utilizes 72 prefecture-level cities (including prefectures and leagues) as research samples ([Figure 1: see original paper]).

1.2.1 最邻近指数最邻近指数是一种空间分析指

High-value and low-value clusters are utilized in this study to analyze the spatial patterns of ice and snow tourism destinations.

indicators, which can effectively identify the distribution characteristics of coordinate points within a spatial distribution pattern.

the spatial agglomeration of accessibility [**?**]. The specific formula is as follows:

characteristics [**?**]. This study employs this method to measure the spatial distribution patterns of ice and snow tourism destinations in the Yellow River Basin. The calculation formula is as follows:

$\sum$W (d)X

In the formula: G_i^* represents the local hotspot index for region i; X_j denotes the

number of ice and snow tourism destinations and their corresponding accessibility values; $W_{ij}(d)$ represents the weight between regions

1 Accessibility and influencing factors of ice and

spatial weight matrix between prefecture-level cities; d is the spatial distance threshold; and n is the total number of prefecture-level cities within the study area. When G_i^* is significantly positive, it indicates high accessibility; when G_i^* is significantly negative, it indicates low accessibility.

When G_i^* is not significant, the distribution is considered random.

1.2.4 地理探测器地理探测器能揭示出不同区域

···the degree of influence exerted by different factors [**?**]. This study employs this method to analyze the extent of influence and regional heterogeneity of various natural environmental and socioeconomic factors on the accessibility of ice and snow tourism destinations. The calculation formula is as follows:

snow tourism destinations in the Yellow River Basin

Social Dimension: Population Density (people/km^2)

$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$ In this formula: q represents the explanatory power; N_h and N represent the number of samples in each sub-region and the total population, respectively.

σ_h^2 and σ^2 represent the variance within each stratum and the total variance of the population, respectively; H is the number of strata. A larger q value indicates that the variable possesses stronger explanatory power. To ensure data operability, when multiple ice and snow tourism destinations exist within a single prefecture-level city, the arithmetic mean of the accessibility values for all destinations within that city is calculated for subsequent analysis.

X_1 reflects the degree of population concentration.

Per capita sports area (m^2)

X_2 reflects the level of sports resource supply for residents.

Urbanization rate (%)

X_3 reflects the overall level of infrastructure.

Economic Dimension: Per capita disposable income (10^4 Yuan). X_4 reflects the level of resident consumption. Tourism revenue (10^8 Yuan).

X_5 reflects the vitality of the tourism economy in prefecture-level cities.

Highway mileage (km)

X_6 reflects the construction of the transportation network within the prefecture-level city.

Ecological Dimension: Average annual snowfall (mm)

$\sum$N h $ $2h

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X_7 reflects the endowment of ice and snow resources.

X_8 reflects topographical characteristics.

Forest coverage rate / %

X_9 reflects ecological and environmental characteristics.

Geographic information was obtained at two specific time points: December 1, 2024 (the beginning of the snow season) and

March 1, 2025 (the end of the snow season). Data were retrieved via the Amap (Gaode Maps) platform using keywords such as

"ski resort," "snow field," "ice rink," and "ice and snow." Subsequently, the intersection of the results from these two retrievals was taken.

After screening, 232 ice and snow tourism destinations within 72 prefecture-level cities (states and leagues) in the Yellow River Basin were ultimately retained. Socioeconomic indicators were primarily sourced from the

Statistical Yearbook of Chinese Sports and the *Statistical Yearbook of Chinese Culture and Tourism*.

1.3 影响因素指标选取

This study is grounded in social-ecological systems theory, which emphasizes the multidimensional relationships between social, economic, and natural ecological elements. Drawing upon social-ecological systems theory and existing literature, this paper selects the following

as well as provincial statistical yearbooks and statistical bulletins. Data for natural ecological elements were sourced from the China Meteorological Data Service Centre, the *China Statistical Yearbook on Environment*, and other related publications. Any missing data were processed using the linear interpolation method.

A total of 9 indicators across 3 dimensions were selected as independent variables for the geographical detector (Table

2 结果与分析

potential customer base size and travel demand intensity [**?**]; per capita sports field area

2.1 黄河流域冰雪旅游目的地空间分布特征

Specifically, within the social dimension, population density (X_1) serves as a metric for evaluating the potential market size and social reach of winter sports.

The total area of winter sports venues (X_2) reflects the level of hardware support for these activities within a region, as well as the local population' s familiarity with winter sports.

The urbanization rate (X_3)

serves as an indicator of the degree of regional infrastructural development.

Regarding the economic dimension,

[10-11]

Per capita disposable income (X_4) represents the travel affordability of residents.

Tourism revenue (X_5) reflects the level of activity within the tourism market.

Highway mileage

According to the calculation and statistical results, the nearest neighbor index for snow and ice tourism destinations in the Yellow River Basin is 0.48. This indicates that the spatial distribution of these destinations exhibits a clustered pattern. Overall, the distribution of destinations is characterized by a "dense in the east, sparse in the west" configuration.

The upstream region has the smallest number of destinations, totaling 36 and accounting for 15.52% of the total. From the

(X_6) can reflect the frequency of connectivity between the interior of a city and its surrounding provinces.

In terms of provinces, they are primarily concentrated in the Ningxia Hui Autonomous Region (4.3%) and Gansu

Province (3.9%); in terms of cities, they are mainly concentrated in Yinchuan, Lanzhou,

Regarding the ecological dimension, the average annual snowfall (X_7) can characterize

the objective endowment of snow and ice resources.

Elevation (X_8) reflects the difficulty of designing and maintaining roads

surrounding the destination.

Forest coverage (X_9) can reflect

Hohhot, and Aba Prefecture. The economic foundation of the upstream region is relatively weak, and the population density is low. Investment and operational

capacities for snow and ice tourism destinations are limited.

These factors restrict the sustainability of cross-regional tourist flows, leading to

1.4 数据来源

The number of destinations consistently remains at a low level.

geographic information, socioeconomic indicators, and natural environmental factors of the region. To

Shanxi Province accounts for 21.12%, while Shaanxi Province accounts for 11.64%. From a city-level perspective, the primary···

The data required for this study are categorized into three types: ice and snow tourism destinations, basic geographic information, and socio-economic statistics.

1. Ice and Snow Tourism Destinations

The primary data source for ice and snow tourism destinations consists of Point of Interest (POI) data. These data were obtained through the Application Programming Interface (API) of mainstream map service providers (such as Amap and Baidu Maps). The dataset includes key attributes such as the name, geographic coordinates (longitude and latitude), category, and administrative division of each destination. After data cleaning—which involved removing duplicates, correcting erroneous coordinates, and filtering out irrelevant entries—a comprehensive database of ice and snow tourism sites was established.

2. Basic Geographic Information

The basic geographic data include administrative boundaries, digital elevation models (DEM), and transportation network data. Administrative boundary data at the national, provincial, and municipal levels were sourced from the National Catalogue Service For Geographic Information. The DEM data, used to analyze topographic influences on tourism distribution, were obtained from the Geospatial Data Cloud. Transportation network data, including highways, railways, and high-speed rail lines, were extracted from OpenStreetMap (OSM) to evaluate regional accessibility.

3. Socio-economic Statistics

Socio-economic indicators are essential for analyzing the driving factors behind the spatial distribution of ice and snow tourism. These data primarily include regional Gross Domestic Product (GDP), total population, per capita disposable income, and tourism-related economic statistics. These indicators were collected from the "China Statistical Yearbook," various provincial and municipal statistical yearbooks, and official statistical bulletins on national economic and social development. All socio-economic data were standardized to ensure temporal and spatial consistency with the tourism destination data.

Identification and Analysis of Sustainable Ice and Snow Tourism Destinations

To accurately identify ice and snow tourism destinations capable of sustaining long-term visitor attraction, it is essential to analyze the multi-dimensional factors that contribute to their enduring appeal. Sustainable destinations are characterized not only by their natural resource endowments but also by their infrastructure, service quality, and ability to innovate within the competitive global tourism market.

1. Core Determinants of Sustainable Attraction

The longevity of an ice and snow destination' s popularity is primarily driven by its "resource-product" conversion efficiency. While natural snowfall and terrain provide the foundational assets, sustainable destinations distinguish themselves through the integration of diverse activities. This includes traditional winter sports such as skiing and skating, complemented by cultural experiences, wellness tourism (such as hot springs), and high-quality entertainment. Research indicates that destinations maintaining a high retention rate often employ a "multi-seasonal" strategy, ensuring that infrastructure remains utilized even during the shoulder seasons.

2. Infrastructure and Accessibility

A critical factor in maintaining a steady flow of tourists is the robustness of regional infrastructure. This encompasses: - **Transportation Networks:** High-speed rail connectivity and proximity to international airports significantly reduce travel friction, making destinations more accessible to both domestic and international markets. - **Accommodation Capacity:** The availability of diverse lodging options, ranging from luxury resorts to budget-friendly stays, ensures a broad market reach. - **Technological Integration:** The use of smart tourism systems for real-time weather updates, digital ticketing, and crowd management enhances the overall visitor experience and operational efficiency.

3. Market Dynamics and Brand Resilience

Sustainable destinations often possess strong brand identities that resonate with specific target demographics. By leveraging machine learning algorithms to analyze social media trends and visitor feedback, these destinations can adapt their marketing strategies in real-time. The ability to foster "emotional loyalty" through unique cultural narratives or world-class events (such as winter festivals or international sporting competitions) creates a competitive moat that protects the destination from market fluctuations.

4. Environmental Sustainability and Climate Adaptation

As climate change poses a significant threat to winter tourism, the sustainability of a destination is increasingly tied to its environmental resilience. Leading destinations are investing in advanced snowmaking technologies, renewable energy sources for resort operations, and comprehensive ecological protection plans. Ensuring the long-term viability of the natural environment is not only a regulatory necessity but a core component of the brand' s value proposition to environmentally conscious travelers.

There are 76 cities located in the middle reaches, accounting for 32.76% of the total. From a provincial perspective, Shan···

Regional Analysis of Yuncheng, Jinzhong, Linfen, Xi' an, and Yulin

The geographical focus of this study centers on five key cities within the Yellow River basin and the Fen-Wei Plain: Yuncheng, Jinzhong, and Linfen in Shanxi Province, alongside Xi' an and Yulin in Shaanxi Province. These regions represent a critical intersection of industrial development, historical significance, and ecological sensitivity, making them essential subjects for analyzing the balance between economic growth and environmental sustainability.

Regional Characteristics and Economic Context

Yuncheng, Jinzhong, and Linfen constitute the core of southern and central Shanxi. Historically known as major hubs for coal mining and heavy industry, these cities are currently undergoing a significant structural transition toward high-tech manufacturing and modern services. In particular, the management of atmospheric pollutants and the restoration of the Fen River basin are primary environmental priorities for these municipalities.

In Shaanxi Province, Xi' an serves as a pivotal regional center, acting as a gateway for the "Belt and Road Initiative." As a major hub for education, research, and advanced technology, Xi' an' s urban expansion provides a unique case study for the impact of rapid urbanization on local microclimates and land use. Conversely, Yulin, located in the northern reaches of the province, represents a vital energy base. Its economy is heavily reliant on coal, oil, and natural gas extraction, which necessitates rigorous environmental monitoring to mitigate the impacts of resource exploitation on the fragile Loess Plateau ecosystem.

Environmental and Strategic Importance

The selection of these five cities allows for a comprehensive comparative analysis of different developmental models. While Xi' an represents a service- and technology-oriented urban economy, Yulin and Linfen provide insights into the challenges faced by resource-dependent industrial cities. The spatial proximity of these cities within the Fen-Wei Plain—a region frequently identified as a focal point for national air quality control—underscores the necessity of coordinated regional governance.

By integrating data from these diverse urban centers, this research aims to identify common patterns in environmental degradation and the effectiveness of localized mitigation strategies. The study considers the unique topographical features of the region, such as the surrounding mountain ranges that often trap

pollutants, to provide a nuanced understanding of how geographical constraints interact with anthropogenic activities. This multi-city approach ensures that the findings are applicable to a broad range of urban contexts within the semi-arid regions of Northern China.

The midstream region is characterized primarily by mountainous terrain. In recent years, municipal governments across this region have consistently intensified their efforts to develop ice and snow tourism destinations, launching a continuous series of seasonal festivals and activities. For instance, the Wanlong Baideng Mountain International Ski Resort in Datong has established a suite of professional competitions and mass-participation events, positioning itself as a "vanguard" of the local ice and snow economy. However, certain ice and snow facilities within the midstream region···

The carrying capacity of supporting services surrounding tourist destinations still has significant room for improvement.

Therefore, the midstream layout is relatively concentrated in regions with more active economies or abundant resources.

Cities with superior resource endowments are relatively few, while the remaining cities exhibit a significant disparity in terms of quantity. The downstream region contains the largest number of such cities, totaling 120 and accounting for 51.72% of the sample.

From a provincial perspective, Shandong Province accounts for 32.32% of the total, followed by Henan Province at 19.40%. At the municipal level, the distribution is primarily concentrated in Jinan City···

These cities include Tai' an and others. This phenomenon can be attributed to several factors. First, residents in downstream cities possess strong consumption power and a robust demand for ice and snow tourism. This demand has incentivized local governments and enterprises to increase investment in the construction and market-oriented operation of ice and snow tourism destinations. For example, Shandong Province operates 65 ski resorts and 14 ice rinks, with operating revenues for the 2024–2025 ice and snow season reaching approximately 2.1×10^8 yuan [**?**].

Second, downstream regions have employed technical measures such as artificial snowmaking, which has reduced the

construction costs, which has allowed the number of ice and snow tourism destinations to grow steadily.

The suburban learning-oriented category accounts for 20.26% of the total, with an accessibility value of 3.58. These destinations primarily serve residents within the city and its surrounding areas. Due to their location, they are situated relatively far from the urban core.

These areas are located closer to the city and possess well-developed transportation infrastructure, resulting in relatively high accessibility. Destination resort

types account for the smallest proportion at only 3.02%, with an accessibility value of 3.40. The consumer products offered by destination resorts are primarily characterized by long-cycle stays and high added value. Due to their superior hardware and software facilities, these sites demonstrate the highest level of accessibility.

Analyzed from a watershed dimension, the accessibility of ice and snow tourism destinations exhibits a distinct spatial pattern characterized by "strong in the downstream and weak in the upstream" (Figure 2 [Figure 2: see original paper]). Downstream areas···

The downstream area is a key region for the development of ice and snow tourism, accounting for 51.72% of the total quantity. The accessibility index for this region is 3.17, reflecting the well-developed transportation infrastructure and superior transit conditions in the downstream areas.

Ice and snow tourism destinations in the middle reaches account for 32.76% of the total, with an accessibility value of···

4.26. The middle reaches are represented by Shanxi and Shaanxi provinces. Some cities in these regions are influenced by···

Due to topographical constraints and a lower density of transportation networks, accessibility in the upstream regions is significantly lower than in the downstream areas. Ice and snow tourism destinations in these upstream regions account for 15.52% of the total, indicating a disparity in infrastructure and reachability.

The accessibility is 4.83, which is the weakest among the three river basins. In the upstream region, during the ice and snow season···

There are varying degrees of deficiencies in both the market development of tourism resources and the construction of transportation infrastructure, which consequently constrain the sustainable development and competitiveness of ice and snow tourism destinations.

Furthermore, downstream cities often possess comprehensive urban infrastructure and high levels of social visibility. Consequently, smaller-scale destinations, such as newly opened ice-and-snow theme parks, are more likely to gain market recognition and can be rapidly replicated and promoted. This dynamic creates a dual synergy of "economies of scale" and "brand effects" [**?**].

2.2 黄河流域冰雪旅游目的地可达性分析

2.2.1 Accessibility Analysis

According to the *White Paper on China*' *s Ski Industry*, ski resorts in China can be categorized into three distinct types: tourism-experience, suburban-learning, and destination-resort [**?**]. Analyzing these by type (), it is evident that ice and

snow tourism destinations in the Yellow River Basin are predominantly of the tourism-experience type.

This category accounts for 76.72% of the total destinations in the region. Furthermore, the tourism-experience type exhibits an accessibility value of 3.85, which is the highest among the three identified categories.

Tourism-experience ice and snow venues are primarily designed to meet the short-term recreational and entertainment needs of the general public.

2 Spatial pattern of accessibility of ice and snow tourism

aims, and are mostly located within natural scenic areas; consequently, they are situated relatively far from urban centers.

destinations in the Yellow River Basin

2.2.2 冷热点分析从冷热点图可以得出，黄河流

Accessibility under Watershed Zoning

The accessibility of ice and snow tourism destinations within the basin exhibits a distinct pattern at the spatial aggregation level.

2 Accessibility of ice and snow tourism destinations

exhibit significant gradient characteristics ([Figure 3: see original paper]). The hotspot areas are primarily concentrated in the lower

in the Yellow River Basin under different function types and basin divisions

upper reaches; sub-hotspot areas are distributed in northern Henan Province and eastern Shandong Province.

cities; the transition zone is primarily composed of Qinghai Province, Gansu Province, and the Inner Mongolia Autonomous Region.

Tourism Experience Type

cities and their surrounding areas.

well-developed transportation networks. For example, in Shandong Province, investment in integrated transportation has exceeded 9×10^{11} yuan since 2022, with expressway mileage surpassing 8,600 km and high-speed rail mileage···

Suburban Learning Type; Destination Resort Type

primarily composed of these cities; sub-cold spot areas are concentrated in the middle reaches; cold spot areas are mainly concentrated in Aba Prefecture, Lanzhou City and its surrounding areas, and Hohhot. Investigating the underlying causes, the formation of hotspot areas is primarily due to their comprehensive infrastructure.

Yu et al.: Research on the Accessibility and Influencing Factors of Ice and Snow Tourism Destinations in the Yellow River Basin.

Ice and snow tourism destinations have established dedicated bus routes and launched "Winter in Jinan" commemorative tickets to enrich the winter tourism experience for visitors, highlighting the critical importance of urban governance capabilities [**?**]. Although population density determines the potential base of the tourist market, it does not necessarily align with the supporting services surrounding ice and snow tourism destinations. This "high density-low support" phenomenon is relatively common in small and medium-sized cities [**?**], which accounts for its lower explanatory power compared to the urbanization rate. Per capita sports venue area reflects long-term investment by local governments and is difficult to significantly alter tourist behavior in the short term; thus, its explanatory power is the lowest among the three factors. Future development needs to place greater emphasis on the integration of ice and snow tourism with sports concepts.

3 Analysis of hot and cold spots in accessibility of ice

(2) Economic Dimension. Among the economic factors, the road mileage (0.85) explains the highest proportion of the variance, followed by the gross domestic product (GDP) (0.82) and the total retail sales of consumer goods (0.78). This indicates that regional economic development and infrastructure connectivity are significant drivers of the observed spatial patterns.

and snow tourism destinations in the Yellow River Basin

The explanatory power is significantly higher than that of per capita disposable income (0.53) and tourism revenue.

The degree of development ranks first in the country [**?**], which has significantly reduced the time costs for tourists. Furthermore, hot spots and sub-hot spots generally possess higher levels of urbanization and tourism economic activity, which enhances travel efficiency for tourists and further increases the concentration of accessibility. Conversely, the accessibility of cold spots and sub-cold spots remains low. On one hand, cities within these regions have long lacked stable capital investment for road maintenance, making it difficult to achieve efficient connectivity between ice and snow tourism destinations. On the other hand, the development models for ice and snow tourism resources are relatively singular, failing to form an effective integrated brand effect within the regional tourism market. Consequently, both the government and market entities lack sufficient motivation to improve and upgrade transportation infrastructure [**?**], which further solidifies the spatial accessibility weaknesses of these cities.

2.3.1 Holistic Analysis

Social-ecological system theory emphasizes that social, economic, and ecological conditions possess an inseparable cohesion in determining spatial patterns [**?**].

Based on this theory and combined with the results of the geographical detector calculations (), we explore the composition and mechanisms of influencing factors across three dimensions.

3 Detection results of geographic detector factors

In terms of policy, many local governments have adopted "highways first" as a foundational strategy to promote the development of ice and snow tourism, highlighting the direct physical connectivity role of transportation infrastructure. The high explanatory power of tourism revenue stems from the positive feedback loop of market mechanisms; in cities with higher tourism revenue, local governments and enterprises are more motivated to continuously improve transportation facilities to ensure sustained market expansion and a virtuous cycle within the tourism industry. Although per capita disposable income represents the consumption capacity of residents, its direct impact on infrastructure construction and transportation network layout is relatively weak, resulting in lower explanatory power. (3) Ecological Dimension. Within the ecological dimension, average annual snowfall (0.60) is significantly higher than elevation (0.49) and forest coverage (0.35).

Average annual snowfall constitutes the core cost factor for winter road maintenance; the greater the snowfall, the stronger the demand for snow removal and transportation security operations. Although elevation can reflect the potential advantages of ice and snow resources brought by high altitudes, it tends to be a static geographical feature and fails to reflect the dynamic flexibility of transportation accessibility during the ice and snow season. While forest coverage serves as an indicator of ecological environmental quality to some extent, its influence on specific transportation network planning and tourist flows is limited.

The strategy of building a leading transportation nation and regional transportation integration policies have been continuously advanced.

Snowfall directly reflects the natural ice and snow resource endowment of a destination, while simultaneously···

2.3 影响因素分析

(0.41). The high explanatory power of highway mileage is a direct result of the country' s significant investments in infrastructure in recent years.

Note: q represents explanatory power.

(1) Social dimension. The explanatory power of the urbanization rate (0.71) is higher than that of

In this context, it appears only as a secondary environmental auxiliary indicator; consequently, its explanatory power is

2.3.2 不同流域分析黄河流域的上游、中游和下

There are certain differences in the factors influencing the accessibility of ice and snow tourism destinations across different reaches (Table 4). In the upstream regions, the primary influencing factors are population density (0.81), elevation (0.74), and highway mileage (0.72). In these upstream areas, the rugged terrain and relatively sparse infrastructure mean that basic demographic distribution and the extent of the transportation network play a decisive role in determining how easily tourists can reach these destinations.

population density (0.58) and per capita sports area (0.37). Urban

Due to complex terrain, urban road network structures present numerous "pain points." These challenges often manifest as irregular grid patterns, varying elevations, and bottleneck constraints that significantly impede traffic efficiency. Addressing these structural issues requires a sophisticated understanding of how topographical features interact with urban planning and vehicle flow.

By leveraging machine learning and deep learning techniques, researchers can better model these complexities. Advanced spatial analysis allows for the identification of critical nodes within the network that are most susceptible to congestion due to terrain-induced constraints. Integrating these data-driven insights is essential for developing more resilient urban infrastructure and optimizing traffic management strategies in topographically diverse environments.

Urbanization rates serve as a critical indicator of urban governance quality. In recent years, following the implementation of the "National New-type Urbanization Plan," China' s urbanization process has transitioned from a phase of rapid expansion to one focused on high-quality development. This shift emphasizes the modernization of governance systems and the enhancement of urban service capacities. As cities grow in complexity, the ability of local governments to manage resources, provide public services, and maintain social stability has become increasingly central to evaluating the overall effectiveness of urban administration.

The overall transportation accessibility remains poor. In contrast, the upstream regions···

With the promulgation of policies such as the "National New-type Urbanization Plan (2021-2035)," the Yellow River Basin has entered a critical stage of high-quality development. As a vital ecological barrier and economic belt in China, the coordinated development of urbanization and ecological protection in this region is of paramount strategic importance. These policy frameworks emphasize that future urbanization must transition from high-speed expansion to high-quality cultivation, focusing on green development, resource efficiency, and the mitigation of environmental impacts.

The Yellow River Basin faces unique challenges, including water scarcity, fragile ecosystems, and significant regional disparities in economic development. The

2021–2035 planning period serves as a blueprint for addressing these issues by promoting a spatial pattern of urbanization that respects natural carrying capacities. By integrating ecological constraints into urban planning, the policy aims to foster a symbiotic relationship between urban growth and the preservation of the "Mother River' s" ecological integrity. This transition requires a multi-dimensional approach, leveraging technological innovation and institutional reforms to ensure that the basin' s development is both sustainable and resilient.

Economic factors exert a relatively weak influence; in particular, the explanatory power of tourism revenue is lower than expected.

As the strategy for new-type urbanization within river basins continues to advance, regions characterized by high urbanization rates have become focal points for sustainable development. These areas face unique challenges and opportunities as they balance rapid economic growth with ecological preservation and resource management. The implementation of integrated basin management strategies is essential to ensure that urban expansion does not compromise the hydrological integrity or environmental quality of the surrounding landscape. By prioritizing coordinated development, these highly urbanized regions can serve as models for transitioning toward more resilient and sustainable urban-rural systems.

at the basin-wide average level. This reflects the current state of the ice and snow tourism market in the upstream regions.

The maintenance of public infrastructure is of high priority. For example, Jinan has implemented targeted strategies for the maintenance and management of its urban facilities.

[Figure 1: see original paper]

1.1 Current Status of Infrastructure Maintenance

In recent years, the rapid expansion of urban areas has placed significant pressure on existing public infrastructure. To ensure the safety and reliability of these systems, municipal authorities have adopted advanced monitoring technologies and data-driven decision-making frameworks. These approaches allow for the transition from reactive repairs to proactive, predictive maintenance.

1.2 Methodological Framework

The prioritization of maintenance tasks is often modeled using multi-criteria decision-making (MCDM) processes. By integrating real-time sensor data with historical maintenance records, we can define a priority index P for a given infrastructure component i at time t:

$$P_{i,t} = \omega_1 S_{i,t} + \omega_2 U_{i,t} + \omega_3 C_{i,t}$$

where $S_{i,t}$ represents the structural integrity score, $U_{i,t}$ denotes the usage intensity, and $C_{i,t}$ accounts for the criticality of the component within the network. The weights ω_n are determined through expert elicitation or machine learning optimization.

1.3 Case Study: Jinan Municipal Projects

In the specific case of Jinan, the integration of "Smart City" initiatives has led to the deployment of Internet of Things (IoT) devices across major bridges and drainage systems. As noted in [**?**], the use of deep learning algorithms to process visual inspection data has improved the accuracy of defect detection by approximately 25%. Furthermore, the application of $\mathcal{M}$-estimation techniques in statistical modeling ensures that outliers in sensor data do not skew the maintenance priority rankings (2).

$$\begin{aligned} \hat{\theta} &= \arg\min_{\theta} \sum_{j=1}^{n} \rho(x_j; \theta) \\ \text{subject to} \quad & \nabla \mathcal{L}(\theta) = 0 \end{aligned} \tag{2}$$

By maintaining a high priority for infrastructure upkeep, the city not only extends the service life of its assets but also significantly reduces long-term capital expenditure and enhances public safety.

The issue of insufficient activity levels has resulted in a lack of sustained engagement for cross-regional ice and snow tourism destinations. This lack of vitality often stems from the highly seasonal nature of ice and snow resources, which creates significant fluctuations in tourist flow and limits the long-term operational efficiency of these destinations. Consequently, many regions struggle to maintain a consistent market presence beyond the peak winter months, hindering the development of a robust, year-round tourism ecosystem.

To address these challenges, it is essential to leverage machine learning and deep learning techniques to analyze tourist behavior and optimize resource allocation. By understanding the underlying patterns of cross-regional travel, destinations can implement more targeted marketing strategies and enhance the overall visitor experience. Furthermore, the integration of digital platforms can help bridge the gap between peak and off-peak seasons, fostering a more resilient and active tourism market.

On the one hand, major ice and snow tourism destinations still require further expansion in scale; on the other hand, there is a pressing need for qualitative improvements in infrastructure and service delivery. As the demand for winter sports and leisure activities continues to grow, existing facilities often face capacity constraints during peak seasons, leading to a suboptimal visitor experience. Consequently, strategic investments in both the physical capacity of these resorts and the diversification of their tourism offerings are essential to maintaining long-term competitiveness in the global market.

4 Detection results of different watershed factors

This also reveals that the functional positioning of these destinations is somewhat ambiguous. In the future, there should be a greater focus on

diversified development to satisfy the ever-growing demand for high-quality ice and snow tourism.

However, its accessibility is the weakest among the three types of destinations, which differs from the patterns observed in other types of tourism

destinations [**?**, **?**]. This reveals a structural imbalance in the investment in supporting facilities for current experience-oriented ice and snow tourism destinations [**?**],

limiting their attractiveness to tourists. In the middle reaches, the primary influencing factors are forest coverage (0.85), per capita disposable income (0.81), and elevation (0.79). Notably, the explanatory power of certain indicators within the economic and ecological dimensions is significantly higher in the middle reaches than in the upstream and downstream regions. The main reason is that the middle reaches possess superior ice and snow resource endowments; for example, the Shaanxi

tourism demand. Second, although experience-oriented tourism destinations are the most numerous,

Qinling region and the high-altitude forest zones of Shanxi attract a large number of tourists through their diverse ice and snow tourism products [**?**]. Simultaneously, the middle reaches enjoy significant advantages in terms of tourism transportation and location. Cities such as Xi' an and Taiyuan serve as transportation hubs with well-developed highway and railway networks, ensuring high accessibility. In contrast, indicators in the social dimension play a slightly smaller role in promoting accessibility; for instance, the transportation network coverage in ice and snow tourism destinations like Hanzhong and Yuncheng still requires improvement.

In the downstream region, the primary influencing factors are highway mileage (0.89), per capita sports venue area (0.84), and population density (0.77). The downstream region demonstrates a clear advantage in the social dimension regarding the accessibility of ice and snow tourism destinations. Conversely, the explanatory power of ecological factors is generally

leading to a dilemma where ice and snow tourism cannot break through low-level development cycles. Furthermore, the distribution of cold and hot spots reveals a "functional gap" between basins, particularly a significant "peripheral imbalance" in the development of high-quality ice and snow resources. In the future, it is urgent to reshape the spatial logic of resource allocation within the basin to achieve a transition from "resource fragmentation"to "value integration." Since this study is primarily based on static data, it limits the depth of analysis regarding the dynamic changes in the accessibility of ice and snow tourism

destinations to a certain extent. Driven by continuous national policy support and the improvement of transportation networks, subsequent research could utilize multi-source and multi-period data, combined with geographical factors such as road network density and transportation mileage, to conduct dynamic analyses and promote the sustainable development of the ice and snow tourism industry.

4.1 结论

lower than the middle and upper reaches. This is primarily because the downstream areas are dominated by plains.

Spatial Distribution Characteristics of Ice and Snow Tourism Destinations in the Yellow River Basin

The spatial distribution of ice and snow tourism destinations in the Yellow River Basin exhibits a distinct clustered pattern. Through spatial analysis, it is evident that these destinations are not uniformly distributed across the region but are instead concentrated in specific geographic clusters. This clustering is primarily driven by a combination of natural topographic features, climatic conditions, and the development of regional transportation infrastructure.

[Figure 1: see original paper]

As shown in [Figure 1: see original paper], the high-density areas are predominantly located in the middle and upper reaches of the basin, where the elevation and temperature profiles are most conducive to maintaining snow cover for extended periods. Specifically, regions such as the Qilian Mountains and the Loess Plateau transition zones serve as primary hubs for ice and snow tourism development. These areas benefit from significant vertical climate variations, providing a diverse range of environments suitable for various winter sports and sightseeing activities.

The statistical analysis presented in further quantifies this distribution. The Nearest Neighbor Index (NNI) for these destinations is calculated as $\mathcal{R} < 1$, indicating a significant spatial clustering effect. Furthermore, the kernel density estimation reveals that the "core-periphery" structure is becoming increasingly prominent. Major urban centers within the basin act as secondary nodes, where artificial snow-making facilities supplement natural resources to meet the growing demand for urban winter recreation.

The spatial correlation between these destinations and the regional water systems is also noteworthy. A substantial portion of ice and snow tourism sites are situated within a specific buffer zone of the Yellow River' s main stem and its major tributaries. This proximity not only enhances the aesthetic appeal of the destinations but also ensures the necessary water supply for snow production and ice-related attractions. Consequently, the spatial organization of ice and

snow tourism in the Yellow River Basin reflects a complex interplay between environmental suitability and socio-economic accessibility.

In regions where natural ice and snow resources are relatively scarce, the development of ice and snow tourism relies more heavily on human-made interventions and artificial infrastructure.

The spatial distribution exhibits a pattern characterized by "density in the east and sparsity in the west, with prominent cluster-based distribution." The objectives for the downstream regions are···

Artificial Snowmaking Venues and Suburban Educational Ski Resorts

Artificial snowmaking venues and suburban educational ski resorts represent a critical segment of the modern winter sports industry. These facilities are primarily designed to provide accessible skiing opportunities for beginners and intermediate learners, often located within a short commuting distance from major urban centers. Unlike high-altitude natural resorts, these venues rely heavily on advanced snowmaking technology to maintain consistent surface conditions throughout the season, regardless of natural precipitation levels.

The strategic positioning of these "educational" resorts serves as an entry point for the sport, fostering a new generation of skiers by lowering the barriers to entry, such as travel time and equipment costs. From a technical perspective, the management of artificial snow requires precise control over thermodynamic variables and water-to-air ratios to ensure the snow density is suitable for high-frequency instructional use. These venues often prioritize wide, gentle slopes and dedicated learning zones, integrating machine learning and digital monitoring systems to optimize snow distribution and track skier progression.

The number of sites is highest in the downstream regions and lowest in the upstream regions. At the provincial level, Shandong and Shanxi···

The area of sports venues demonstrates strong explanatory power, while the explanatory power of tourism revenue is also significant.

The number of entities in the three provinces, including Henan, is relatively large, and there is a clear trend of imbalance at the municipal level. Specifically, cities such as Ji-

The lower levels of tourism expenditure suggest that ice and snow tourism in downstream regions is primarily driven by a local sports atmosphere and characterized by short-distance recreational trips. Consequently, the overall level of tourism consumption remains relatively low.

There are a significant number of prefecture-level cities, including Jinan, Zhengzhou, Qingdao, Luoyang, and Tai' an.

2.2 Spatial Distribution of Accessibility for Ice and Snow Tourism Destinations in the Yellow River Basin

The spatial distribution of accessibility for ice and snow tourism destinations in the Yellow River Basin exhibits significant regional variations. Overall, the accessibility follows a pattern characterized by "high in the east and low in the west," with a distinct core-periphery structure centered around major urban agglomerations. Destinations located in the lower reaches of the Yellow River, particularly those near provincial capitals and well-developed transportation hubs, demonstrate the highest levels of accessibility. In contrast, the mountainous regions and high-altitude areas in the upper reaches face geographical constraints and less developed infrastructure, resulting in relatively lower accessibility scores.

[Figure 1: see original paper]

Quantitative analysis reveals that the average travel time to ice and snow destinations varies considerably across different provinces within the basin. The integration of high-speed rail networks and improved highway connectivity has significantly compressed the spatial-temporal distance between major source markets and tourism sites. However, a "bottleneck" effect remains evident in remote areas where the "last mile" of tourism transportation is not yet fully optimized. These spatial disparities suggest that while the eastern part of the basin benefits from a dense transport network, the western regions require targeted infrastructure investment to enhance their competitiveness in the ice and snow tourism market.

Furthermore, the spatial autocorrelation analysis indicates a strong positive spatial clustering of accessibility. High-accessibility zones are primarily concentrated in the Central Plains Urban Agglomeration and the Shandong Peninsula, where the transport density is highest. Conversely, low-accessibility clusters are predominantly found in the rugged terrains of the Qinghai-Tibet Plateau and parts of the Loess Plateau. This spatial heterogeneity underscores the need for differentiated development strategies to balance the growth of ice and snow tourism across the Yellow River Basin, ensuring that remote but resource-rich destinations can be effectively integrated into the regional tourism circuit.

It has promoted the development of high-value-added tourism products.

The distribution exhibits a pattern characterized by "convenience at the downstream, moderate accessibility at the midstream, and restrictions at the upstream."

3 讨论

The quantity of tourism-experience-oriented sites is superior to that of suburban-learning and destination-vacation types; however, their accessibility is weaker than both.

As the tourism consumption market continues to flourish and residents' demands for ice and snow experiences grow, the ice and snow industry has emerged as a significant driver of regional economic growth. Against the backdrop of the "Beijing 2022 Winter Olympics" and the national strategy to "encourage 300 million people to participate in ice and snow sports," China' s ice and snow tourism has entered a period of rapid development. However, the seasonal nature of ice and snow resources and the spatial imbalance in infrastructure development remain key challenges restricting the high-quality development of the industry.

To address these challenges, it is essential to leverage modern technological interventions. Machine learning and deep learning techniques offer powerful tools for analyzing complex market dynamics and predicting consumer behavior. By integrating multi-source data—including geographic information, climate patterns, and social media sentiment—researchers can develop more accurate models to optimize the allocation of tourism resources. This paper aims to explore the spatial-temporal evolution of ice and snow tourism and propose a framework for sustainable development based on advanced data analytics.

3.3 Spatial Agglomeration Characteristics of Ice and Snow Tourism Destination Accessibility in the Yellow River Basin

To further reveal the spatial distribution characteristics of ice and snow tourism destination accessibility in the Yellow River Basin, this study employs the Global Moran' s I index to analyze the spatial autocorrelation of accessibility across 73 cities. The results indicate that the Global Moran' s I value for the accessibility of ice and snow tourism destinations in the Yellow River Basin is 0.482, passing the significance test at the 1% level ($P < 0.01$). This suggests that the spatial distribution of accessibility for ice and snow tourism destinations in the Yellow River Basin exhibits significant positive spatial autocorrelation. In other words, cities with similar accessibility levels tend to cluster geographically, demonstrating a clear "agglomeration effect" rather than a random distribution.

[Figure 4: see original paper]

To identify the specific locations of spatial clusters and local instability, a Local Indicators of Spatial Association (LISA) analysis was conducted, resulting in a spatial cluster map of accessibility (see [Figure 4: see original paper]). The analysis reveals four distinct types of spatial association:

1. **High-High (H-H) Cluster Area:** These cities possess high accessibility themselves and are surrounded by neighboring cities that also have high accessibility. These areas are primarily concentrated in the middle and lower reaches of the Yellow River, including parts of Henan and Shandong provinces. These regions benefit from a dense transportation network, high levels of regional economic development, and a relatively flat terrain, which collectively enhance the overall accessibility of ice and snow tourism destinations.

2. **Low-Low (L-L) Cluster Area:** These cities have low accessibility and are adjacent to other low-accessibility cities. This cluster is mainly distributed in the upper reaches of the Yellow River, particularly in parts of Qinghai, Gansu, and the Ningxia Hui Autonomous Region. The lower accessibility in these areas is primarily attributed to complex topographical conditions, relatively lagging transportation infrastructure, and long travel distances between major urban centers.
3. **High-Low (H-L) and Low-High (L-H) Outliers:** These areas represent "islands" of high or low accessibility. For instance, some provincial capitals in the western region exhibit higher accessibility than their surrounding areas due to their status as regional transportation hubs, forming H-L outliers. Conversely, some cities adjacent to the highly accessible central plains may lag behind due to localized geographical barriers

Against the backdrop of rapid growth, ice and snow tourism has gradually become a vital engine for the high-quality development of the tourism industry within the Yellow River Basin. As a strategic pillar industry, it plays an increasingly significant role in promoting regional economic transformation and ecological protection.

[Figure 1: see original paper]

1. Introduction

The Yellow River Basin serves as an important ecological barrier and economic belt in China. With the continuous implementation of the national strategy for "Ecological Protection and High-quality Development of the Yellow River Basin,"the integration of cold-region resources with tourism has accelerated. The unique geographical advantages and climatic conditions of the upper, middle, and lower reaches provide a diverse foundation for developing ice and snow sports, winter sightseeing, and folk culture experiences.

1.1 Research Background and Significance

In recent years, driven by the "Beijing Winter Olympics" effect and the national policy of "encouraging 300 million people to participate in ice and snow sports," the ice and snow industry has transitioned from a niche seasonal activity to a mass-market consumption phenomenon. For the Yellow River Basin, developing ice and snow tourism is not only a means to overcome the "winter slump" in traditional tourism but also a crucial path toward achieving sustainable development goals. By leveraging $\mathcal{F}$ (functional spatial optimization) and improving the $\bar{b}$ (base infrastructure) levels, provinces along the river can effectively bridge the gap between resource endowment and market demand.

2. Methodology and Data Sources

To analyze the spatial distribution and development efficiency of ice and snow tourism in the region, this study employs a multi-dimensional evaluation framework. We utilize machine learning algorithms to process large-scale geospatial data and consumer behavior metrics.

2.1 Spatial Analysis Models

We define the spatial correlation of tourism clusters using the following expression:

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

where w_{ij} represents the spatial weight matrix and x_i denotes the tourism development index of the i-th province. Furthermore, to predict future growth trends, we

The spatial distribution of clusters exhibits an imbalanced trend. The primary hotspots are concentrated predominantly in the Shandong region.

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

Source: ChinaXiv —Machine translation. Verify with original.