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Spatial distribution and suitability evaluation of nighttime tourism in Kunming utilizing multi-source data

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ABSTRACT

In the post-pandemic era, nighttime tourism is vital in promoting the diversified development of tourism, enhancing the vitality of cities, and improving reemployment rates. Using Kunming City, China, as an example, this study used multi-theory and multi-source data to construct an evaluation model of the spatial distribution and suitability of nighttime tourism. The projection pursuit model and spatial analysis method were used to reveal spatial distribution and explore the suitability characteristics and spatial differences of nighttime tourism development. Our results revealed the following: (1) nighttime tourism resources showed a 'large aggregation, small dispersion' spatial distribution pattern, which is characterized by a distribution along the railway line; (2) at present, the spatial distribution of nighttime tourism in Kunming displays a pattern of 'taking a high-density large gathering area as the center and extending around; ' and (3) the most suitable nighttime tourism area accounts for 11.83% of the total land area of Kunming; highly suitable area accounts for 17.53%. The general suitable and unsuitable areas accounted for 43.29% and 27.35%, respectively. The results of this study assist in providing a scientific basis for the strategic planning and development of the nighttime tourism industry in Kunming.

1. Introduction

As an important engine for driving consumption, investment, and import and export economic growth, tourism is crucial to the rapid development of China's economy. In the post-pandemic era, the development of tourism has been highly impacted and has suffered unprecedented hardships. According to the World Tourism Council, 62 million jobs have been lost from the global tourism industry. The uncertainty of the pandemic, recovery of the tourism market, and viability of the tourism industry still face many practical difficulties. In this context, cities need to inject new vitality and residents require additional re-employment opportunities. As a type of city-centered tourism activity, nighttime tourism has spatial and temporal characteristics and is capable of addressing the resource conditions of and injecting new vitality into the city. Therefore, developing nighttime tourism can not only meet people's leisure and entertainment needs but can also assist in the development of the regional economy.

Nighttime tourism is a tourism involves tourists and residents and usually occurs from 6 p.m. until 6 a.m. the following day [1]. With upgrades to urban landscape construction and diversification of tourism, nighttime tourism has achieved considerable economic

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benefits; however, it is currently developing spontaneously rather than systematically. Although local and international researchers have explored this field extensively, the primary focus has been on the negative social problems wrought by nighttime tourism, including development strategies, products, and economic benefits [2–5]. Nevertheless, thus far, few studies have investigated the spatial distribution and conducted a suitability evaluation of nighttime tourism. Gu et al. [6] examined the temporal and spatial rules of nighttime tourism activities by recording the location and status of the active population. Cheng et al. [7] superimposed data of nighttime tourism safety incidents with data from a travel agency liability insurance demonstration project and analyzed the spatial and temporal distribution of nighttime tourism safety incidents. Most researchers have used traditional data types to explore the spatial distribution of nighttime tourism. Yet, for nighttime tourism, a relatively new activity [8], using traditional data alone cannot fully reflect the spatial distribution of tourism [9]. Such limitations of these data types have hindered research on the spatial distribution of nighttime tourism.

With the advent of big data, many public source datasets have been used in tourism research, such as point of interest (POI) data [10], GPS positioning data [11], and nighttime lighting data [12]. Compared with traditional data, these emerging public source datasets can be used to obtain reliable spatial information, which ensures research accuracy. Accordingly, such data has been applied to tourism research. For instance, Li et al. applied POI data to explore the spillover effect of tourism space [13]. Meanwhile, Liao et al. explored the spatial differentiation of rural tourism resources and its influencing factors through rural POI data [14]. Nonetheless, the application of such data in nighttime tourism research remains limited having only been applied to explore the relationship between tourism POI and nighttime lighting [15] and that between tourism economy and nighttime lighting [16]. Meanwhile, to date, few studies have used multi-source data to explore the spatial distribution of nighttime tourism.

In this study, we considered Kunming as the research area and constructed a spatial distribution evaluation system and suitability evaluation system for nighttime tourism in the region based on spatial structure theory and communication and space theory. Based on POI data, remote sensing data, network data, and traditional data, the projection pursuit model and spatial analysis method were used to investigate the spatial distribution characteristics of nighttime tourism resources and current nighttime tourism in Kunming, and the area was divided according to the suitability for nighttime tourism. This study evaluates the spatial distribution and suitability of nighttime tourism in Kunming, aiming to understand the current situation and existing problems of nighttime tourism development, explore the relationship and interaction between night tourism resources and other elements of the city, and provide a basis for the subsequent formulation of effective urban planning and management policies. Through the evaluation and suitability analysis of the spatial distribution of nighttime tourism, we can identify the distribution of nighttime tourism in different regions and the potential for nighttime tourism activities and provide a scientific basis for site selection for subsequent night tourism development.

2. Literature review

2.1. Theoretical background

Our literature review and theoretical backing for the study revealed two key theories on which the work was based:

(1) Spatial structure theory: Spatial structure theory regards interrelated components in a certain area as an organic functional body to study the spatial interaction and spatial position relationship between the organic bodies. Thus, it reflects the geographical spatial agglomeration scale and agglomeration degree of the organic bodies. von Boventer [17], a German researcher, was the first to systematically analyze and further develop the theory of spatial structure. He synthesized the views of the pioneers of location theory, such as Danone and Weber, before analyzing the spatial structure at different stages of social development with the supported development theory. He also highlighted the main factors that cause spatial structure differences. In the early twentieth century, western scholars began to introduce the theory of spatial structure to tourism supply and demand [18]. Research in China on tourism spatial structure began later, initially only relying on tourism resources for research [19]. However, with the advancement of research, scholars began to comprehensively analyze the spatial layout of tourist destinations from the perspective of geographical regions and economic relations [20]. That is, the theory of tourism spatial structure can be regarded as the spatial abstraction of tourism components, with different classification methods, such as dynamic tourists, static tourism resources, point-like service facilities, and the regional consumer market. In this way, the spatial structure theory of geography can be applied to the study of nighttime tourism, and the spatial pattern of nighttime tourism can be analyzed from the perspective of nighttime tourism resources and the nighttime economy, which can inform the development of nighttime tourism in tourist destinations as a whole.

(2) Communication and space theory: Jan Gehl believes that human outdoor activities can be summarized into three types: need-based, spontaneous, and social activities [21]. The communication space is where these three activities take place. It is also the place where people communicate and connect in daily life. There should be a key focus on the relationship between the activities in the communication space and the crowd [22]. The theory of communication and space holds that residents and tourists are the key groups in tourism development, making the related research vital [23]. With the continuous development of society and an increase in leisure time, the communication space has naturally become a cultural-ecological environment for people to integrate, blend into nature, and cultivate sentiment. Meanwhile, to meet the needs of various material and spiritual cultures, various production activities and service activities have begun to create a comfortable communication space around the activity trajectory of people. Therefore, as a public communication space, the distribution of nighttime tourism destinations needs to have a certain relationship with tourist activities. In this study, the nighttime tourist Weibo check-in point represents

the tourism vitality of nighttime tourists and offers insights into the distribution of Kunming nighttime tourism under the influence of nighttime tourist vitality.

2.2. Nighttime tourism research

As an emerging tourism activity, nighttime tourism has attracted the attention of many researchers, and the existing research is rich and diverse. Many researchers have focused on the carriers and experience types of nighttime tourism development, stakeholders, and its positive and negative effects [24,25]. Derrien [26] and Bjelajac et al. [3] explored the impact of day and nighttime perception differences on tourists' experience and the role of tourists' imagination in the nighttime experience. Bristow [4] and Pinke-Sziva [5] found that nighttime tourism can not only enrich people's spirituality, but also facilitate economic growth, investment, and employment. Li et al. [27] explored the mechanism of influence of the nighttime tourism atmosphere and found that innovation and cultural contact play a positive role in the development of the nighttime tourism atmosphere and can lead to an unforgettable tourism experience. However, Montmagny Grenier [28] expressed concern about the negative impact and security risks to residents caused by excessive nighttime tourism. These findings promote the strategic development of nighttime tourism, improve the attraction of tourists to nighttime tourism activities, and enrich the existing research.

However, literature analysis reveals that there is little research on space and suitability development in nighttime tourism. As a special tourism activity, nighttime tourism is easily affected by the environment, and its spatial distribution and rational development are different from traditional tourism activities. Therefore, this study attempted to construct a detailed scientific model to explore the spatial distribution and suitability of nighttime tourism and fill the gap in this research field.

3. Materials and methods

3.1. Study area

Kunming is located at 102°10′–103°40′ E, 24°23′–26°22′ N, and the city center is located at 102°42′31′E, 25°02′11′N (Fig. 1). Kunming is located on the central Yunnan–Guizhou Plateau in southwest China, adjacent to Dianchi Lake in the south and surrounded by mountains on three sides. The overall terrain is high in the north and low in the south, gradually decreasing from north to south in a stepwise manner. Kunming serves as the gateway between China and Southeast Asia, South Asia, the Middle East, Southern Europe, and Africa.

Kunming has a subtropical–plateau mountain monsoon climate typical of lower northern latitudes. It has a mild climate, without extreme heat or cold in summer or winter, respectively. This unique climate type means that flowers bloom in Kunming throughout the year, and the vegetation is evergreen. It is known as the famous 'Spring City' and 'Flower City'.

Kunming is one of the top 10 tourist cities in China and is highly regarded as a tourist destination. It has well-known national and provincial scenic spots such as the Stone Forest, Dianchi Lake, and Jiuxiang, as well as many key scenic spots such as the Yunnan Ethnic

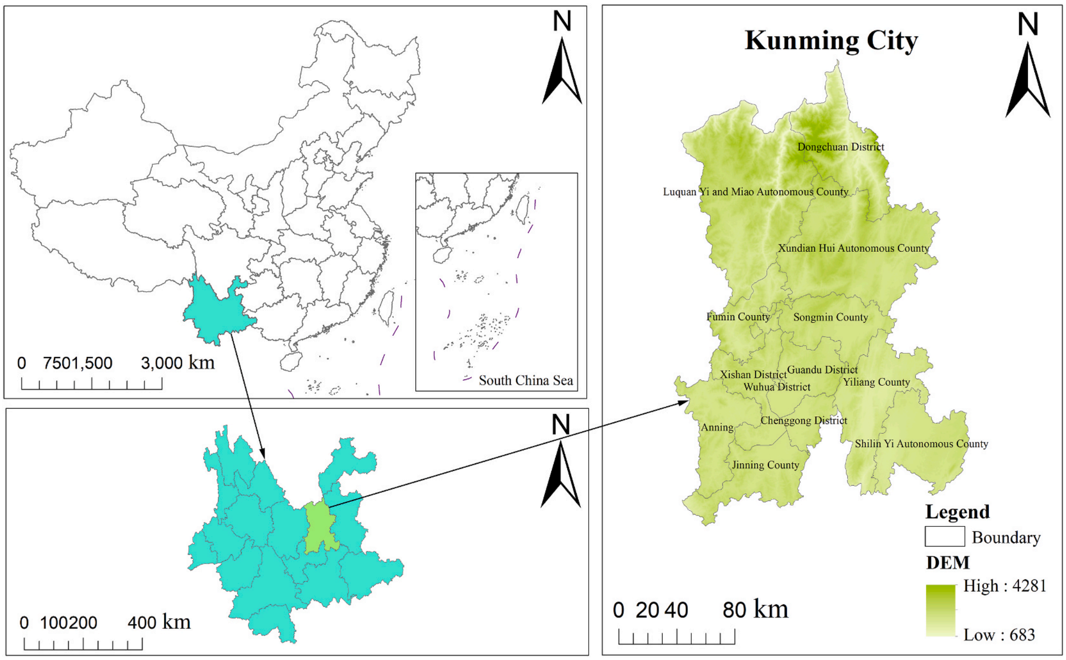

Fig. 1. Geographical location of Kunming.

Village and Xishan Longmen. With the gradual transformation of modern tourism from single sightseeing tourism to compound holiday tourism, nighttime tourism has become an important part of leisure tourism. Notably, the Dounan Flower Market in Kunming and Kunming Old Street-Nanqiang Block have been rated as national nighttime culture and tourism consumption agglomeration areas, which effectively demonstrates the potential and vitality of Kunming nighttime tourism.

3.2. Data sources and processing

The research data used in the study predominantly consists of four parts: First, tourism data, including nighttime tourism resource POI data and nighttime tourist Weibo check-in data, as well as the heat, score, and comment number of Kunming tourist attractions. The POI data used in this study was sourced from the Baidu Map. The data was divided into six categories according to the themes of food, accommodation, transportation, travel, shopping, and entertainment. To reflect the nighttime tourism resources more effectively in Kunming, the data were screened to remove zoos, religious temples, and public transportation that were only open or operated during the day, following which, 12,538 valid data points were obtained. Visitor check-in data was sourced from the Sina Weibo platform [29]. The check-in data was obtained using Python 3.7. The time span for the dataset was from January to December 2021. The data obtained was screened, and the check-in data from 18:00 to 6:00 the next day was selected. Finally, 1151 data points were obtained [30]. The specific data classification is shown in Table 1. The popularity, reviews, and number of reviews of tourist attractions were obtained from the China Ctrip travel website (www.ctrip.com/).

The second was basic geographic data, including administrative boundaries, river systems, road networks, and residential distribution. This type of data was primarily sourced from the National Geographic Information Resource Directory Service System (https://www.webmap.cn/main.do?method=index).

The third was thematic data, including a digital elevation model, light remote sensing data, vegetation coverage, and meteorological data. The digital elevation model (DEM) was derived from the geospatial data cloud, and the spatial resolution was 30 m (https://www.gscloud.cn/). Nighttime lighting data was obtained from the Colorado University of Mining and Technology (https://eogdata.mines.edu/download_dnb_composites.html). WGS-1984 comprised the geographical coordinates of the original nighttime light image obtained. To constrain the dataset to a more specific area, this study used ArcGIS 10.2 to convert the geographical coordinates of the annual image into the projection coordinates of Asia Lambert Conformal Conic, and mask extraction was performed to remove data outside the study area. Vegetation coverage and meteorological data were sourced from the National Earth System Science Data Center (http://www.geodata.cn/).

The fourth was traditional statistical data, including the economy, population, education, tourism, and other data of the study area, mainly from the statistical yearbook of Kunming City.

3.3. Methods

(1) Projection pursuit model: The projection pursuit model (PPM) was first proposed by Friedman and Tukey [31] from Stanford University. Projection pursuit comprises a new statistical method for processing and analyzing high-dimensional data. The main idea is to project high-dimensional data onto low-dimensional (1–3) subspaces and identify projections that reflect the structure or trends in the original high-dimensional data. The main steps include index normalization, construction and optimization of projection index functions, and calculation of the projection eigenvalues [32]. This study mainly used the projection pursuit model to calculate the weight of each index.

(2) Kernel density estimation method: Kernel density estimation is derived from the first law of geography, namely that everything is related. The closer an item is to the nuclear element, the greater the density expansion value, reflecting the spatial heterogeneity and center strength attenuation with distance [33]. It can be used to calculate the area of each unit based on points or broken lines so that each point or broken line is suitable for a smooth conical surface. This study explored the spatial distribution pattern of nighttime tourism resources in Kunming through nuclear density analysis using Eq. (1):

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left[\frac{1}{h}(x - x_i)\right] \tag{1}$$

where $K[\,]$ is the kernel function; h is bandwidth; n is the number of known points in the bandwidth range; d is the dimension of data.

Table 1
Types of tourism resource data and check-in data.

Class	Subdivision	Data Type	Quantity
Nighttime Food Tourism Resources	Chinese restaurants, Western restaurants, Roadside snacks	POI	2292
Nighttime Accommodation Tourism Resources	Apartments, Homestays, Hotels	POI	1819
Nighttime Traffic Tourism Resources	Parking lots, Shared bicycle storage points	POI	1227
Nighttime Sightseeing Tourism Resources	Parks, Scenic Spots, Tourist Attractions	POI	1913
Nighttime Shopping Tourism Resources	Shopping plaza, 24-h convenience store, Supermarket	POI	2783
Nighttime Entertainment Tourism Resources	Cinema, KTV, Bar, Games room, Bath massage	POI	1578
Sina weibo check-in data	January–December 2021 Daily 18:00–6:00 the next day	Check-in Data	1151

Data are sourced from Baidu Maps and Sina Weibo.

(3) Voronoi analysis: Voronoi analysis, that is, Thiessen polygon analysis, is a multilateral graphical representation composed of vertical bisector links between two adjacent resource points. There is only one resource point in each polygon, and the polygon area changes with the spatial distribution of the resource point set. The coefficient of variation (CV) of the Thiessen polygon area is used to measure whether the tourism resource elements and adjacent resource elements in the study area are clustered or dispersed in space (Eq. (2)):

$$CV = \frac{\sqrt{\sum (S_i - S)^2 / n}}{S} \tag{2}$$

where S_i denotes the area of the i th polygon; S is the mean of polygon area; n is the number of polygons; and CV is the polygon area variation coefficient which is often used to measure the relative degree of tourism resources in space.

(4) Nearest neighbor index: The nearest neighbor analysis calculates the average value of the nearest distance between the geographical elements in the spatial distribution and compares it with the average distance in the assumed random distribution, to judge the mutual proximity of the spatial geographical elements, that is, the spatial pattern of the distribution of the elements. The nearest neighbor index is used to compare the aggregation degree of six types of night tourism resources in the study area. Its formula is represented by Eq. (3):

$$ANN = \frac{D_O}{D_E} = \left(\frac{1}{n}\sum_{i=1}^{n} d_i\right) \Big/ \left(\frac{1}{2\sqrt{n/A}}\right) \tag{3}$$

where ANN is the nearest neighbor index; D_O is the nearest distance between geographical feature points; n is the number of samples of tourism resource points; d_i is the distance between the geographical element i point and i point; D_E is the theoretical average distance under the condition of random distribution; A is the area of the study area. When $ANN < 1$, the distribution of regional tourism resources presents an agglomeration distribution; when $ANN > 1$, the distribution of regional tourism resources is discrete; when $ANN = 1$, the distribution of regional tourism resources is random.

(5) Standard deviation ellipse algorithm: The standard deviation ellipse algorithm can be used to describe the distribution direction and distribution trend of points in detail. Five parameters can be obtained by ArcGIS software analysis, where CenterX and CenterY represent the center points of the ellipse. XStdDist and YStdDist are the lengths of the x-axis and y-axis of the ellipse, respectively. Rotation represents the direction angle of the ellipse [10]. The calculation formula for θ direction angle is presented as Eq. (4) [34]:

$$\tan\theta = \frac{\left(\sum_{i=1}^{n}\overline{x_i}^2 - \sum_{i=1}^{n}\overline{y_i}^2\right) + \sqrt{\left(\sum_{i=1}^{n}\overline{x_i}^2 - \sum_{i=1}^{n}\overline{y_i}^2\right)^2 + 4\left(\sum_{i=1}^{n}\overline{x_i}\,\overline{y_i}\right)^2}}{2\sum_{i=1}^{n}\overline{x_i}\,\overline{y_i}} \tag{4}$$

where $\overline{x_i}$ and $\overline{y_i}$ represent the differences between the average center x, y coordinates. Finally, the standard deviation of 15 and 6 axes was determined using Eqs. (5) and (6).

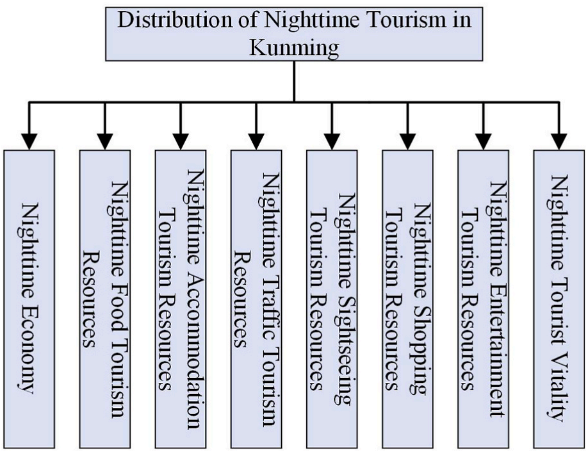

Fig. 2. Kunming nighttime tourism spatial distribution evaluation system.

$$\sigma_x = \sqrt{2}\sqrt{\frac{\left[\sum_{i=1}^{n}(\overline{x}_i cos\ \theta - \overline{y}_i sin\ \theta)^2\right]}{n}} \tag{5}$$

$$\sigma_y = \sqrt{2}\sqrt{\left[\sum_{i=1}^{n}(\overline{x}_i sin\ \theta - \overline{y}_i cos\ \theta)^2\right] \Big/ n} \tag{6}$$

3.4. Index system construction and evaluation standard definition

3.4.1. Construction of the evaluation index system for the present distribution of nighttime tourism in Kunming

Owing to the limitation of time, nighttime tourism differs from traditional tourist attractions as few tourist attractions remain open for nighttime tourism, requiring the associated activities to gradually shift from scenic spots to food, accommodation, traffic, sightseeing, shopping, and entertainment. Therefore, to explore the spatial distribution of nighttime tourism, it is necessary to comprehensively consider these six major associated tourism resources. However, these six elements comprise myriad resource types, many of which are not open at night and are not considered typical tourism activities, leading to spillover effects when exploring the spatial distribution of nighttime tourism. Therefore, under the guidance of the spatial structure theory and the communication and space theory, nighttime tourism resources can be considered as a single index, while two additional indexes—nighttime economy and nighttime tourist vitality—can be incorporated to reduce the spillover effect, thus, constituting the evaluation index for night tourism spatial distribution (Fig. 2). More specifically, nighttime tourism resources were represented by nighttime tourism resource POI data, nighttime economy was represented by nighttime light data, and nighttime tourist vitality was represented by nighttime tourists' Weibo geographic sign-in data.

3.4.2. Construction of Kunming nighttime tourism suitability evaluation index system

Based on the two theories, the basis of tourism resources, sustainability of ecological environmental carrying capacity, role of the tourism market, and level of social consumption were fully considered. Combined with previous research results and the current conditions in the study area, according to the principles of comprehensiveness, scientificity, availability and feasibility, the suitability evaluation index system of nighttime tourism development in Kunming was constructed using four aspects: tourism resources, ecological environment carrying capacity, tourism market, and social economy. There are 20 indexes in total. The system included three layers: target, factor, and index layers (Fig. 3).

3.4.3. Definition of suitability index evaluation criteria

The evaluation criteria of the indicators were determined according to the existing tourism suitability research [35–38], combined with the special geographical location and climate environment of Kunming City and considering the uniqueness of nighttime tourism (Table 2). Among them, each factor is divided into corresponding grades by quantitative classification, and the single factor nighttime tourism suitability grade is classified. Each grade was assigned a score of 1, 3, 5, or 7. The higher the score, the higher the nighttime tourism suitability grade, indicating that the evaluation unit was more suitable for the development of nighttime tourism. The index weight in Table 2 was obtained using the projection pursuit model with 14 administrative regions of Kunming as units.

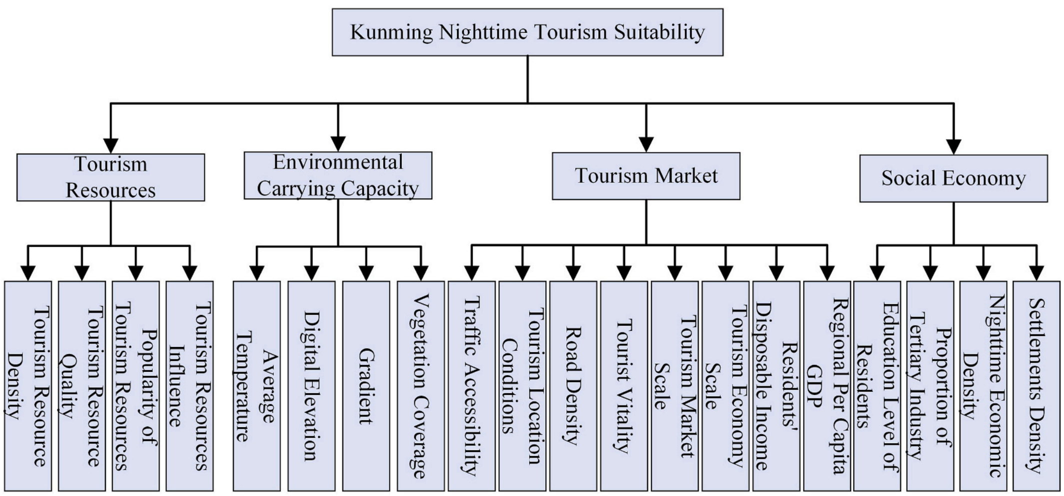

Fig. 3. Kunming nighttime tourism suitability evaluation index system.

Table 2
Evaluation criteria of suitability index.

Element layer	Indicator layer	Index quantification basis	Weight	Evaluation criterion			
				7	5	3	1
Tourism resources	Tourism resource density	–	0.1146	Highest	Higher	General	Lower
	Tourism resource quality	Scene website score	0.0410	Highest	Higher	General	Lower
	Popularity of tourism resources	Number of scenic comments	0.0235	Highest	Higher	General	Lower
	Tourism resources influence	Scenic network heat	0.0677	Highest	Higher	General	Lower
Environmental carrying capacity	Average temperature	°C	0.0124	>10	7–10	4–7	<4
	Digital elevation	km	0.0223	<0.5	0.5–0.8	0.8–1.4	>1.4
	Gradient	–	0.0422	<10	10–15	15–25	>25
	Vegetation coverage	–	0.0011	>60	45–60	30–45	<30
Tourism market	Traffic accessibility	km	0.0465	<1	1–1.5	1.5–2	>2
	Tourism location conditions	Distance to scenic	0.0459	<5	5–15	15–25	>25
	Road density	–	0.0720	Highest	Higher	General	Lower
	Tourist vitality	Weibo check-in number	0.0149	Highest	Higher	General	Lower
	Tourism market scale	Total number of tourists/10,000 people	0.0543	>1500	1000–1500	500–1000	<500
	Tourism economy scale	Tourism revenue/billion yuan	0.0278	>300	200–300	100–200	<100
	Residents' disposable income	Million yuan	0.0534	>4.5	4–4.5	3.5–4	<3.5
	Regional per capita GDP	Million yuan	0.0339	>10	7–10	4–7	<4
Social economy	Education level of residents	Number of middle school students/ 10000 people	0.0840	>2	1–2	0.5–1	<0.5
	Proportion of tertiary industry	–	0.0181	>60	50–60	40–50	<40
	Nighttime economic density	Night light density	0.1165	Highest	Higher	General	Lower
	Settlements density	–	0.1079	Highest	Higher	General	Lower

Data were obtained from literature analysis, expert interviews, and field investigations.

4. Results

4.1. Pattern of nighttime tourism resources

The present study analyzed the nighttime tourism resources in Kunming using the kernel density analysis tool of ArcGIS 10.2. A distribution density map of nighttime tourism resources in Kunming was generated (Fig. 4). The density of nighttime tourism resources in Kunming exhibits a spatial distribution of 'large aggregation and small dispersion,' mainly in a high-density large aggregation area. In addition, Kunming nighttime tourism resources are characterized by a distribution along the railway line.

High-density large gathering areas are mainly distributed at the junction of the Xishan, Wuhua, Guandu, and Panlong Districts. Kunming has famous tourist attractions such as Dianchi Lake, Haigeng Dam, Cuihu Lake, and other national attractions located in these three regions; thus, the tourism industry in the three regions has developed rapidly and extended to include several tourist attractions. In addition, the economic development of the Xishan, Wuhua, and Guandu Districts has also highly benefited Kunming. Therefore, compared with other regions, the infrastructure and living facilities of these three regions have been greatly improved, creating more nighttime tourism resources. Moreover, the railway lines at the junction of the former three districts are intertwined, making it the most densely populated area with good location advantages (Fig. 4).

To explore the aggregation of nighttime tourism resources in Kunming, we conducted Thiessen polygon analysis and average nearest neighbor analysis on nighttime tourism resources. Fig. 5 shows the Thiessen polygon analysis results of nighttime tourism resources in Kunming, and Table 3 shows the average nearest neighbor analysis results of nighttime tourism resources in Kunming.

The minimum polygon area is 0.02255 km^2, the maximum multi-deformation area is 1200.62 km^2, the average value is 74.81, the standard deviation is 172.14, and the CV is 169.95% (Fig. 5). According to Duyckaerts [39], it can be judged that the overall nighttime tourism resource points in Kunming City are clustered and highly clustered. It can be seen from Table 3 that the nearest neighbor index of nighttime tourism subdivision resources in Kunming is far less than 1, and the absolute value of Z is far greater than 2.58. Therefore, the nighttime tourism subdivision resources in Kunming show significant aggregation distribution. In addition, comparing the nearest neighbor index of different subdivided tourism resources, it can be found that the nearest neighbor index of nighttime entertainment tourism resources is the smallest, and the nearest neighbor index of nighttime sightseeing tourism resources is the largest. Regarding the subdivided resources of nighttime tourism in Kunming, the aggregation degree of entertainment resources is the highest and that of sightseeing resources is the lowest.

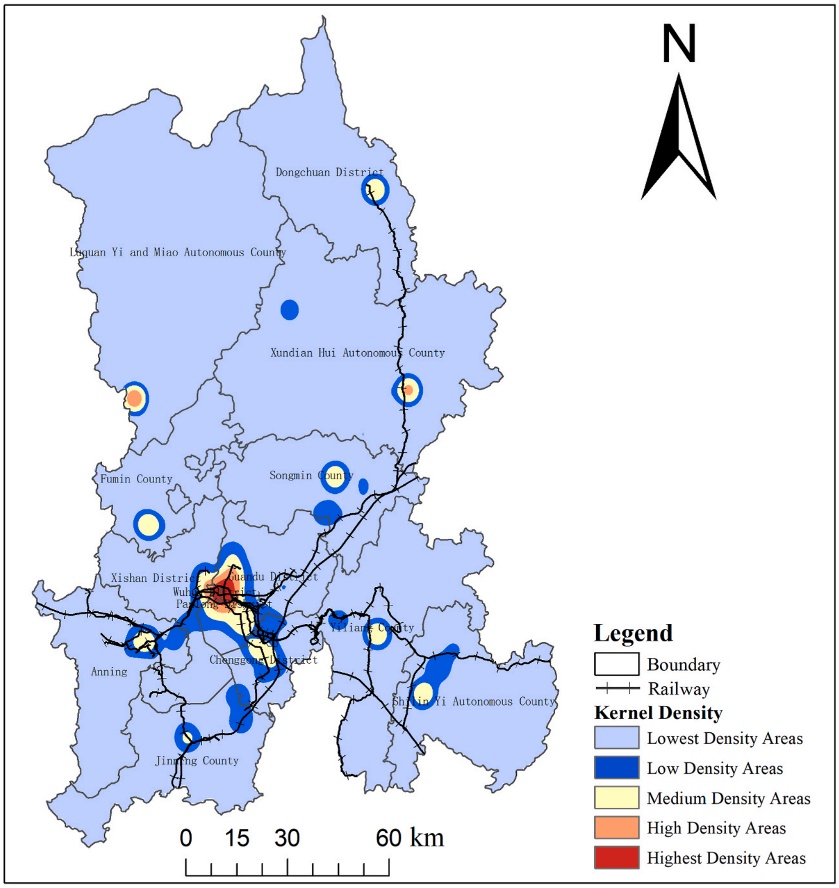

Fig. 4. Nuclear density map of nighttime tourism resources in Kunming.

4.2. Investigation of the present spatial distribution of nighttime tourism

4.2.1. Calculating the projection value of nighttime tourism spatial distribution

To calculate the contribution of each index more accurately according to the spatial distribution of nighttime tourism in Kunming, the spatial distribution of the eight indicators was first gridded, and a planar fishing network diagram of the eight indicators was generated in a 3 × 3 km grid. Second, the planar fishing net data of each index were derived, the projection pursuit model was used to calculate the projection value of each index, and the evaluation model of nighttime tourism spatial distribution in Kunming was constructed (Eq. (7)). Finally, the projection values of each grid data were calculated according to the model, and the spatial distribution of nighttime tourism in Kunming was visualized through ArcGIS. Due to the excessive number of grids, the projection data for only the first 30 grids are presented in Table 4.

$$NTSD = 0.2933 * NF_{2j} + 0.2688 * NA_{3j} + 0.3042 * NT_{4j} + 0.5350 * NS_{5j} + 0.3450 * NP_{6j} + 0.2395 * NM_{7j} + 0.1171 * NV_{8j} + 0.5223 * NE_{1j} (i = 1, 2, 3, 4, 5, 6, 7, 8; j = 1, 2, 3, \ldots, m) \tag{7}$$

where NTSD represents the spatial distribution of nighttime tourism, NE represents the nighttime economy; NV represents nighttime tourist vitality; NF represents nighttime food tourism resources; NA represents nighttime accommodation tourism resources; NT represents nighttime traffic tourism resources; NS represents nighttime sightseeing tourism resources; NP represents nighttime shopping tourism resources; and NM represents nighttime entertainment tourism resources.

4.2.2. Analysis of the spatial distribution index of nighttime tourism

The direction of projection obtained by the PPM can be regarded as the index weight [40]. Therefore, among the eight indicators that make up the model, the importance degrees are: nighttime tourism resources (0.5350) > nighttime economy > (0.5223) > nighttime shopping tourism resources (0.3450) > nighttime traffic tourism resources (0.3042) > nighttime food tourism resources (0.2933) > nighttime accommodation tourism resources (0.2688) > nighttime entertainment tourism resources (0.2395) > nighttime tourist vitality (0.1171).

Nighttime sightseeing tourism resources ranked first, indicating that the spatial distribution of nighttime tourism is in line with the

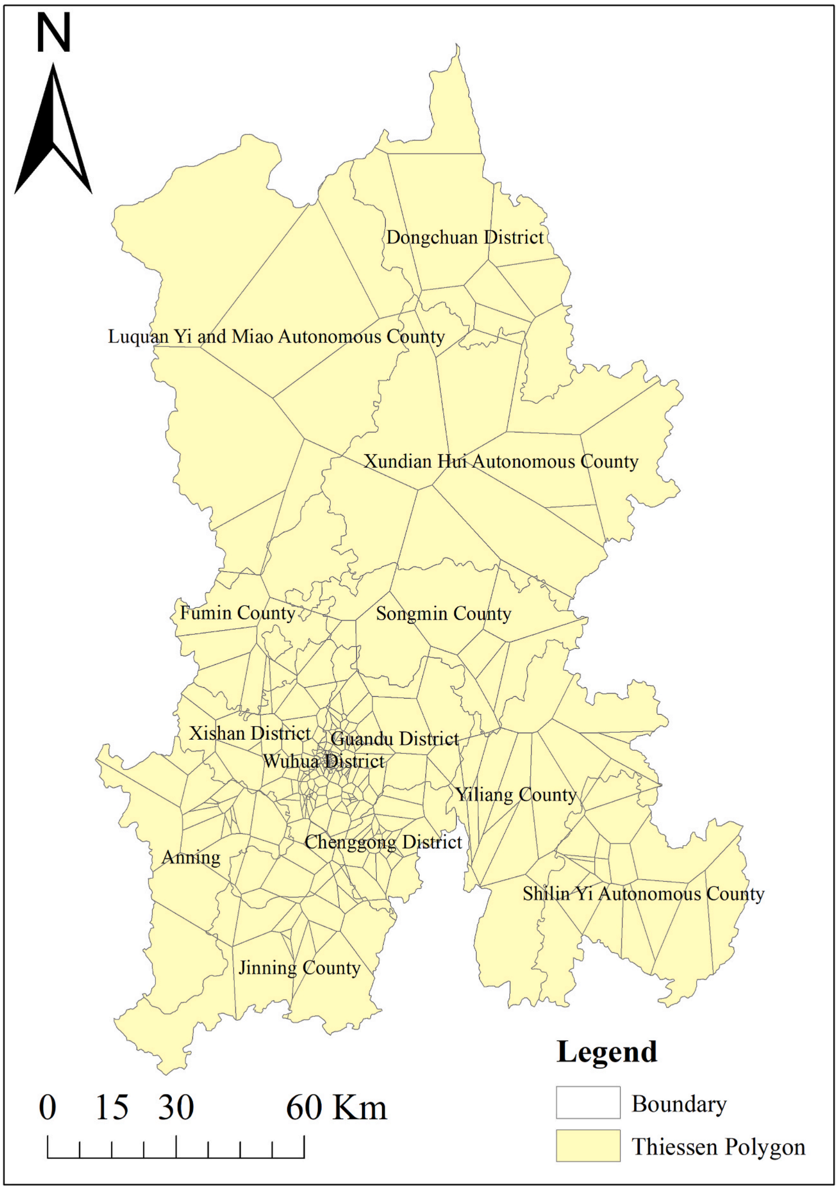

Fig. 5. Tyson polygon distribution map of nighttime tourism resources in Kunming.

Table 3
Nighttime tourism subdivision resources nearest neighbor analysis.

Type of nighttime tourist resource	Nearest neighbor ratio	Z	P
Food	0.108	−81.68	0.000
Accommodation	0.128	−71.160	0.000
Traffic	0.139	−57.724	0.000
Sightseeing	0.172	−69.255	0.000
Shopping	0.112	−89.581	0.000
Entertainment	0.085	−69.319	0.000

The analysis was performed using ArcGIS software. The proximity ratio was calculated by dividing the number of nighttime tourism resources within a certain radius by the total number of resources. The z-score and p-value were used to test the statistical significance of the clustering pattern. Data were sourced from Baidu Maps.

Table 4
Projection values of partial grids.

Grid Number	Projection value	Grid Number	Projection value	Grid Number	Projection value
1	0.0041	11	0.0000	21	0.0016
2	0.0036	12	0.0000	22	0.0028
3	0.0016	13	0.0039	23	0.0011
4	0.0000	14	0.0000	24	0.0087
5	0.0000	15	0.0060	25	0.0006
6	0.0011	16	0.0180	26	0.0261
7	0.0125	17	0.1316	27	0.0000
8	0.0009	18	0.0676	28	0.0000
9	0.0000	19	0.0016	29	0.0000
10	0.0056	20	0.0074	30	0.0062

The analysis was performed using R software. Grid Number represents the number of each grid, and Projection Value represents the comprehensive value of night tourism resources, nighttime economy, and nighttime tourist activities for each grid. Data were sourced from Baidu Maps, Sina Weibo, and the Colorado School of Mines.

spatial distribution of traditional tourism. Traditional tourism resources remain the most important factors affecting spatial distribution. The weight of the nighttime economy and nighttime sightseeing tourism resources were similar. This indicates that the nighttime economy forms the pillar of nighttime tourism activities and is the most important factor affecting the spatial distribution pattern of tourism. Among the remaining five elements of nighttime tourism, nighttime shopping, traffic, and food had the greatest impact on the spatial distribution of nighttime tourism. This indicates that these three types of tourism activities have become

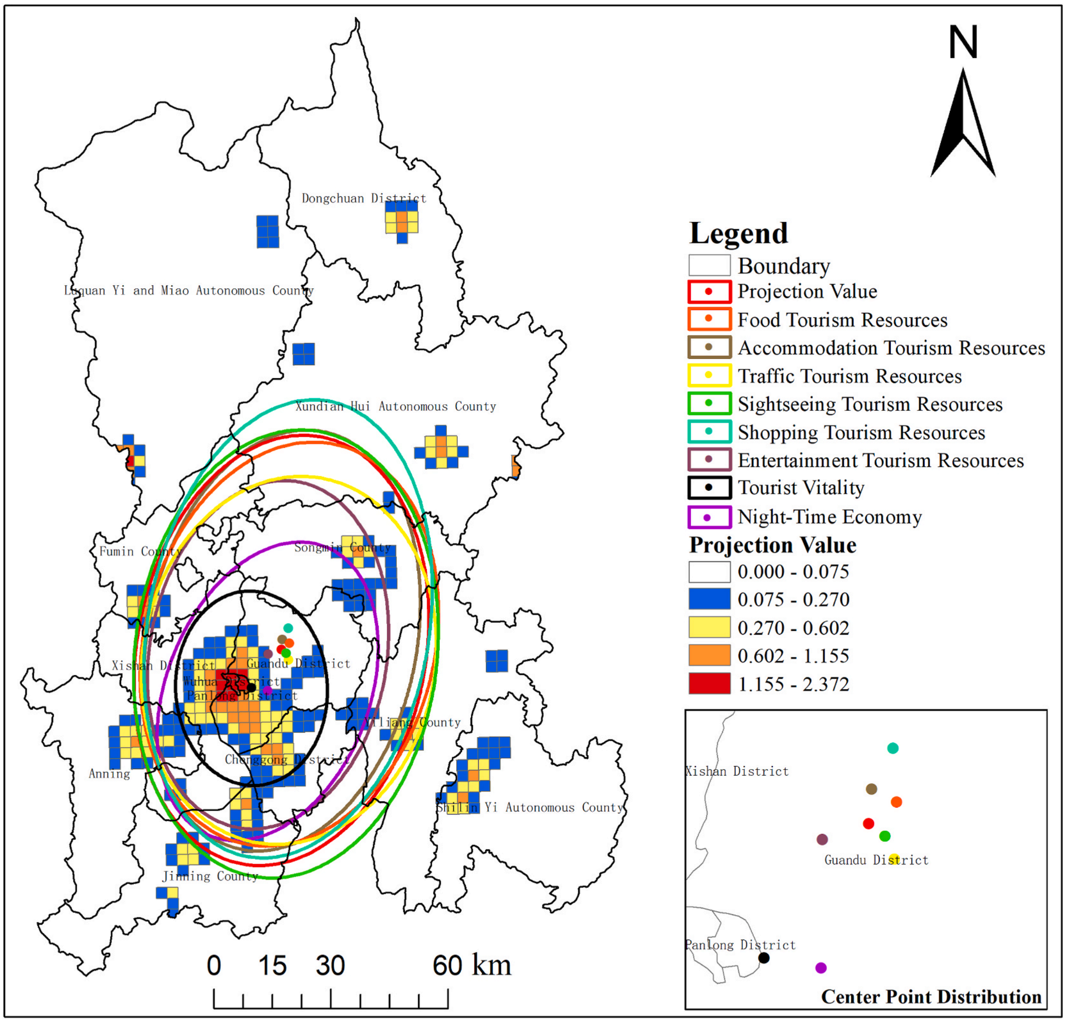

Fig. 6. Spatial distribution map of nighttime tourism in Kunming.

indispensable to nighttime tourism. The weight of nighttime accommodation and entertainment resources was relatively low, having a limited influence on the spatial distribution of nighttime tourism. Finally, the nighttime tourist vitality had the least influence on the spatial distribution. This indicates that the development of nighttime tourism activities, like traditional tourism, is still based on tourism resources attracting tourists. However, the projection value of 0.1171 shows that the vitality of nighttime tourists has a certain degree of influence on the spatial distribution of nighttime tourism.

In summary, the eight indicators were divided into four levels. The main influencing factors are nighttime sightseeing tourism resources and the nighttime economy. The necessary influencing factors include nighttime shopping tourism resources, nighttime traffic tourism resources, and nighttime food tourism resources. The general influencing factors were nighttime accommodation tourism resources and nighttime entertainment tourism resources, and the supplementary influencing factor was nighttime tourist vitality.

4.2.3. *Investigating the present spatial distribution of nighttime tourism*

The projection value of nighttime tourism spatial distribution in Kunming was visualized using ArcGIS10.2, and the projection value and eight indexes of nighttime tourism spatial distribution were analyzed using the standard deviation ellipse tool (Fig. 6, Table 5).

The spatial distribution of nighttime tourism in Kunming is represented by a spatial distribution pattern of 'taking a high-density large gathering area as the center and extending to the surroundings,' accompanied by the scattered distribution of high-density small gathering areas (Fig. 6). The high-density gathering areas of nighttime tourism are mainly distributed at the junction of the Wuhua, Xishan, Guandu, and Panlong Districts, as well as the central area of the Chenggong District. This is similar to the spatial distribution of nighttime tourism resources, which are affected by local tourism, economy, infrastructure, and transportation. The difference is that the high-density gathering area of nighttime tourism in Kunming diverges outward to form four medium-high density gathering zones, which extend to Anning City, Jinning District, and Yiliang County, and these areas connect other scattered nighttime tourism gathering areas.

From the center point and coverage of the nighttime tourism projection value in Fig. 6, the central point of the spatial distribution of nighttime tourism is situated in the Panlong District and is biased in the direction of the Guandu District. This indicates that the Panlong and Guandu Districts are at the center of the spatial distribution of nighttime tourism in Kunming. The main scope of the distribution of nighttime tourism in Kunming includes the Chenggong, Guandu, Panlong, Wuhua, and Jin-ning Districts; Yiliang County; Songming County; Xundian Autonomous Region; Xishan District; and Anning City. This distribution range includes almost all of the high-density gathering areas for nighttime tourism and the areas for sporadic low-density gatherings. The short half axis (east–west direction) of the nighttime tourism spatial distribution is 35.557 km, and the long half axis (north–south direction) is 54.160 km. This shows that the distribution of nighttime tourism in Kunming has an east–west aggregation and a certain dispersion in the north–south direction. The oblateness of the spatial distribution ellipse of nighttime tourism is 0.343. This indicates that the spatial distribution of nighttime tourism has a certain direction. Given that the inclination angle of the ellipse is 14.965°, combined with Fig. 1, the spatial distribution of nighttime tourism in Kunming presents the distribution pattern of 'east–west aggregation, north–south dispersion' and the distribution trend of 'northeast–southwest'.

The center point of each index is distributed around the center point of the projection value, and the coverage of the projection value is between the distribution range of each index. Table 1 shows that the short half axis, long half axis, angle, and slope of the nighttime tourism projection values are close to the average of the eight indicators. Thus, the spatial distribution of nighttime tourism projection values fully considers the range, dispersion, deviation angle, and direction of other indicators in spatial distribution.

4.3. *Suitability analysis of nighttime tourism resources in Kunming*

All data were reclassified according to the rating criteria shown in Table 2; additional data reclassification results are shown in Fig. 7. Based on the spatial analysis grid weighted superposition method, pixel superposition analysis was carried out to obtain the

Table 5
Standard deviation ellipse data.

Resource type	Short half axis/km	Long half axis/km	Angle	Flat Rate
Nighttime food tourism resources	37.941	53.582	17.391	0.292
Nighttime accommodation tourism resources	35.157	55.674	14.824	0.369
Nighttime traffic tourism resources	38.197	48.404	13.970	0.211
Nighttime sightseeing tourism resources	39.456	58.854	10.695	0.330
Nighttime shopping tourism resources	36.731	60.527	13.763	0.393
Nighttime entertainment tourism resources	31.009	45.922	13.318	0.325
Nighttime economy	26.462	40.670	25.489	0.349
Nighttime tourist vitality	19.817	25.426	1.096	0.221
Mean value	33.096	48.632	13.818	0.311
Projection value	35.557	54.160	14.965	0.343

The analysis was performed using ArcGIS software. Short half axis and long half axis represent the dispersion of the distribution; Angle indicates the directional trend of the distribution; Flat Rate reflects whether there is a strong directional trend in the distribution. Data were sourced from Baidu Maps, Sina Weibo, and Colorado School of Mines.

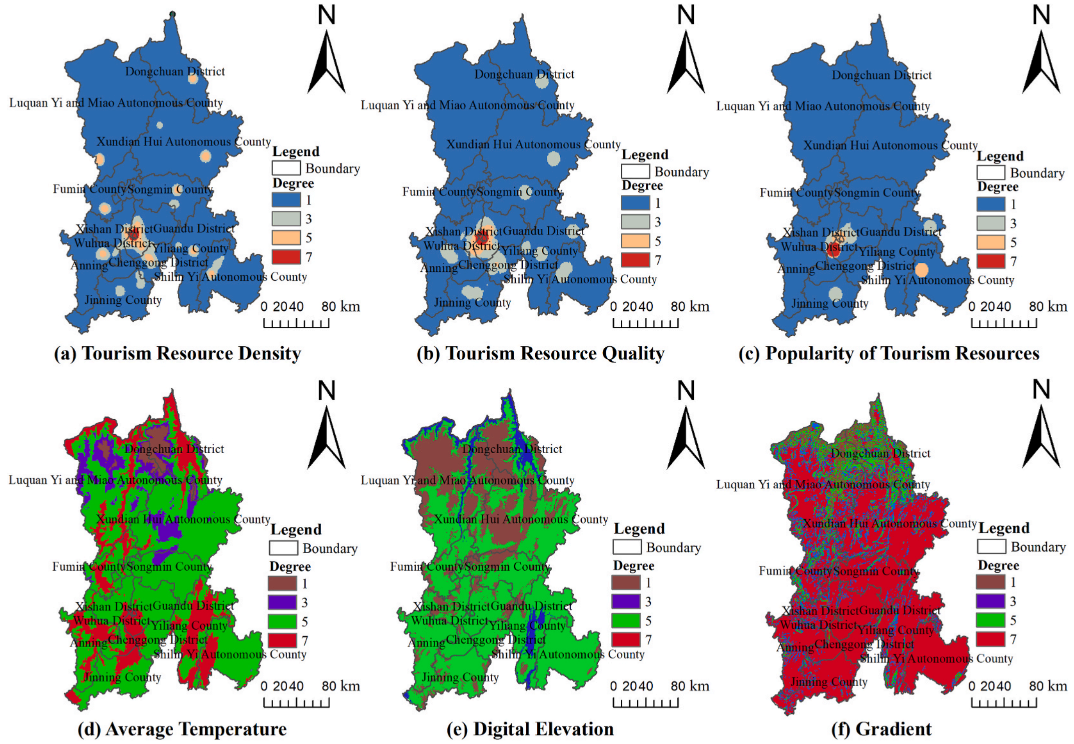

Fig. 7. Spatial distribution map of the suitability index. (a) The density distribution of tourism resources. (b) The quality distribution of tourism resources. (c) The distribution of popularity of tourism resources. (d) The average temperature distribution. (e) The distribution of digital elevation. (f) The distribution of gradient.

spatial distribution map of nighttime tourism development suitability in Kunming, and the natural breakpoint method was used to divide the nighttime tourism development suitability into four grades: most suitable, highly suitable, generally suitable, and unsuitable areas (Fig. 8, Table 6).

The suitability index of nighttime tourism development in Kunming is between 1.658 and 5.899 (Table 6). The region is primarily dominated by generally suitable areas, followed by unsuitable, highly suitable, and most suitable areas, which account for 43.29%, 27.35%, 17.53%, and 11.83% of the total evaluation area of nighttime tourism in Kunming, respectively. However, some areas of Kunming were not included in the evaluation (e.g., areas covered by water bodies and railway networks).

From the perspective of space, the most suitable areas are mainly distributed in the Xishan, Guandu, Wuhua, Panlong, and Chenggong Districts, with some areas scattered in other administrative regions. In addition, the most suitable areas have obvious near-road and near-water characteristics, which are distributed around railway lines in Kunming and the Dianchi Lake. The highly suitable areas are mainly distributed in the four administrative regions of Anning City, Jinning County, Yiliang County, and Shilin Yi Autonomous County, with their distribution also having a certain proximity. In addition to the main distribution area near the railway, the scattered distribution areas of other regions are also distributed along the railway trunk line. The generally suitable area is divided into two parts by the most suitable area and the highly suitable area. One part is mainly located in Fumin County, Songming County, and Xundian Hui Autonomous County, and the other part is distributed in the southwest border of Anning City and Jinning County and the southeast border of Shilin Yi Autonomous County. The unsuitable areas are distributed in the northern part of Kunming, including Luquan Yi, Miao Autonomous County, and Dongchuan District.

From the perspective of location conditions, the most suitable area is located in the center of Kunming, which is the most economically developed and convenient area in Kunming. The tourism infrastructure and living facilities in the region are sound, the six major tourism resources of food, accommodation, transportation, travel, shopping, and entertainment are fully developed, and the location conditions are obvious. In addition, Dounan Flower Market and Old Street-Nanqiang Block, the two first nighttime consumption clusters in China, are located in this region. The highly suitable areas are concentrated in the central area of Kunming, which has many railway lines passing through the region; thus, transportation is convenient. Moreover, as it possesses several national scenic spots, the region has a good tourism market and sufficient tourism labor force; thus, it has a high potential for nighttime tourism development. Generally, the suitable area is far away from the urban area of Kunming, and the economic development is not good. Most of the areas are located at the boundary of Kunming, and only one railway trunk line passes through it, which is inconvenient for transportation. In addition, there are relatively few high-quality tourism resources in the region, the development potential of tourism resources is relatively limited, tourism infrastructure is less abundant, and the tourist market is relatively narrow. The unsuitable areas are located in the northernmost part of Kunming, with high altitude, special terrain, inconvenient transportation, less employment in

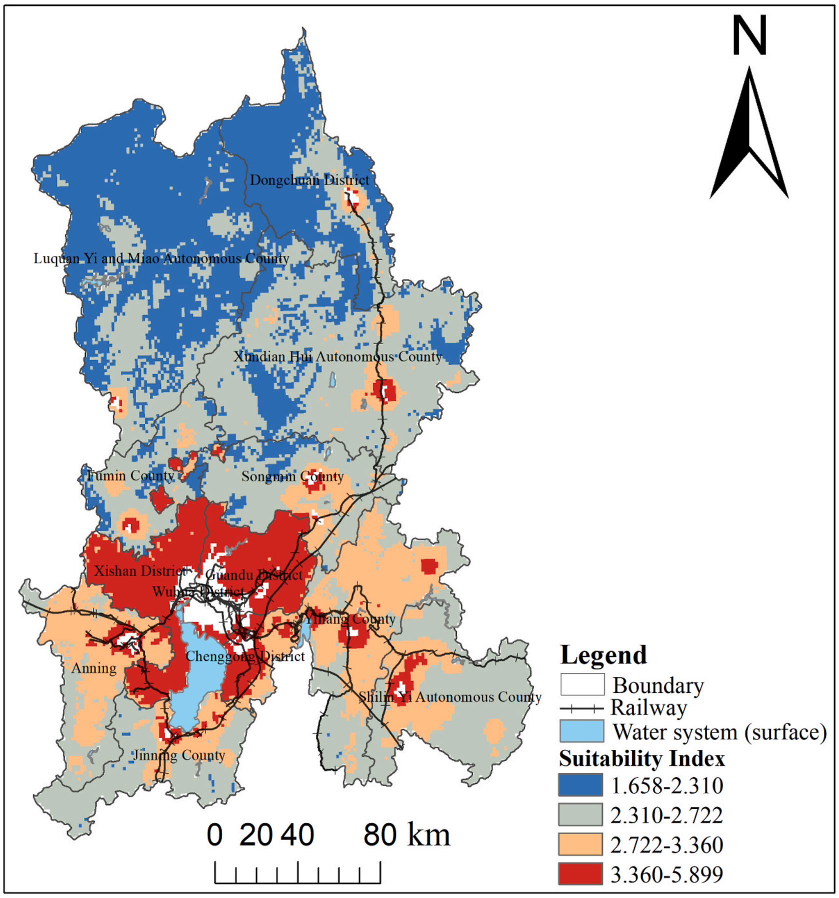

Fig. 8. Kunming nighttime tourism suitability distribution map.

Table 6
Kunming nighttime tourism suitability distribution data.

Types	Suitability index	Area/km^2	Proportion
Most suitable region	3.360–5.899	2371.55	11.83%
Highly suitable area	2.722–3.360	3515.48	17.53%
General suitable area	2.310–2.722	8682.73	43.29%
Unsuitable area	1.658–2.310	5485.31	27.35%

The analysis was performed using ArcGIS software. Data were sourced from Baidu Maps, Sina Weibo, and Colorado School of Mines.

tertiary industries, and imperfect tourism development.

5. Discussion

5.1. Theoretical significance

This study applies spatial structure theory and communication and space theory, which provide an important theoretical support and analytical framework for analyzing the spatial distribution of nighttime tourism. Spatial structure theory emphasizes the relationship between regional economy, tourism resources, and spatial structure. Communication and space theory emphasizes the influence of human vitality on space. Therefore, under the guidance of the two theories, this study constructs an index system including three elements: nighttime economy, nighttime tourism resources, and nighttime tourist vitality. Based on the index system, the spatial distribution and suitability of night tourism in Kunming were studied. The theoretical contributions of this study fall mainly within the following three aspects:

First, as a special tourism activity, the timing of nighttime tourism limits the extent to which tourists can visit scenic areas. Therefore, nighttime tourism resources not only differ from traditional tourism activities such as visiting scenic areas but also differ in all aspects of the development of the six primary tourism resources. Therefore, this study did not use a single tourist attraction as a data source when exploring Kunming nighttime tourism resources, but rather six tourism elements.

Second, to explore the spatial distribution of nighttime tourism in Kunming, this study combined nighttime light remote sensing data and nighttime tourists' network check-in data with nighttime tourism resource data under the guidance of traditional theories. Considering the nighttime economic development of Kunming and the vitality of nighttime tourists, an evaluation model of nighttime tourism spatial distribution based on multi-source data was constructed, which eliminates the deficiency of a single data source to explore the spatial distribution of tourism. In addition, this study also analyzed the elements of the indicators and divided the eight indicators into main factors, necessary factors, general factors, and supplementary factors.

Finally, on the basis of the theoretical guidance of this study, combined with the nighttime tourism resources of Kunming and the current distribution of nighttime tourism in Kunming, and referring to the relevant research of predecessors, an evaluation index system of nighttime tourism suitability was constructed, which makes up for the lack of nighttime tourism spatial exploration, promotes the development of nighttime tourism research, and provides a reference for the effective and reasonable development of nighttime tourism in Kunming.

5.2. Practical significance

To promote the development of nighttime tourism in Kunming and improve the vitality of urban tourism, this study makes the following recommendations:

(1) There were gathering places for nighttime tourism activities in the most suitable area. All the subsequent development of nighttime tourism should focus on the current nighttime tourism hotspots, connecting with other tourism resources, and creating a nighttime tourism consumption network. To maintain the sustainable development of current nighttime tourism, the guiding concept of ecotourism and environmental protection should be incorporated to encourage tourists to improve their awareness of participating in environmental protection and construction while enjoying high-quality nighttime tourism.

(2) Highly suitable areas should form the core areas for the current government to focus on nighttime tourism development. The government should actively respond to the wave of nighttime tourism development and accelerate the process of tourism development in highly suitable areas. There is a lack of typical nighttime tourism venues in the region. We should learn from the nighttime tourism activities situated in the most suitable areas, the combined characteristics of tourism resources, consumption capacity, infrastructure, and other factors in the region, create the first batch of nighttime tourism venues, and use this as a center to extend outward, connect with the most suitable area, and form a closed loop of nighttime tourism activities between the two regions.

(3) Due to the limitation of transportation facilities and tourism resources, the generally suitable area has a relatively narrow tourist market and cannot vigorously develop nighttime tourism activities. However, in addition to foreign tourists, residents also account for a large part of the consumers participating in nighttime tourism. Therefore, the region can consider the consumption capacity of residents, implement a 'small and many' strategy, and develop multiple small-scale nighttime tourism locations.

(4) The unsuitable areas were thus categorized because the terrain is mainly mountainous, with landforms of significance such as the Danxia and Karst landforms. The government should strictly control the development and construction of nighttime tourism in this region.

In addition, nighttime tourism, as a city-centric tourism activity, has spatial and temporal characteristics. To solve the problem of urban resource conditions in time and space, this study puts forward the following suggestions: First, formulate nighttime tourism planning and optimize resource allocation. By re-planning the urban area and rationally distributing a variety of night tourism resources, the distribution efficiency in time and space will be improved. Secondly, strengthen the construction of night tourism infrastructure. Appropriately increase investment in infrastructure construction such as nighttime traffic, scenic lighting, and public safety and improve the coverage and distribution efficiency of various nighttime tourism resources. Finally, use smart city technology to realize the spatial and temporal dynamic scheduling of nighttime tourism resources, improve the efficiency of resource utilization, and encourage the sharing and utilization of night tourism resources.

5.3. Limitations and scope for future study

Given that the research in this study is relatively new in the field of tourism, there is still considerable room to improve the research process and results. First, nighttime light remote sensing data can effectively represent large-scale socio-economic factors. However, few studies have focused on these topics at a fine scale. Therefore, there may be some errors in linking it to the same fishing net as POI and check-in data, resulting in unclear spatial relationships in some areas. Second, to ensure effectiveness, this study takes the data from 2021 as the research object. However, there was less tourist check-in data than for the other datasets. This means that the follow-up time should be extended to obtain more abundant nighttime check-in data. In addition, the study explored the influencing factors of the spatial distribution of nighttime tourism from the aspects of economy, humanities, and nature. A good research direction would also be to analyze the attitude of residents to the development of nighttime tourism.

6. Conclusions

To explore the spatial distribution and suitability of nighttime tourism in Kunming more accurately, this study constructed a spatial distribution model and suitability evaluation model, analyzing the spatial distribution and adaptability of nighttime tourism in Kunming via a projection pursuit model and spatial analysis method. The results are as follows:

(1) The nighttime tourism resources in Kunming show a spatial distribution of 'large aggregation, small dispersion' and are distributed along the railway line. Furthermore, among the nighttime tourism subdivision resources, entertainment resources have the highest degree of aggregation, and sightseeing resources have the lowest degree of aggregation.
(2) The spatial distribution of nighttime tourism in Kunming is spatially distributed with a pattern of 'taking a high-density large gathering area as the center and extending to the surroundings,' accompanied by the sporadic distribution of high-density small gathering areas. It shows the distribution pattern of 'east-west aggregation, north-south dispersion' and the distribution trend of 'northeast-southwest.'
(3) Among the indicators that constitute the spatial distribution of nighttime tourism in Kunming, the main influencing factors are nighttime sightseeing tourism resources and the nighttime economy. The necessary influencing factors include nighttime shopping tourism resources, nighttime traffic tourism resources, and nighttime food tourism resources. The general influencing factors include nighttime accommodation tourism resources and nighttime entertainment tourism resources, and the supplementary influencing factor was nighttime tourist vitality.
(4) The suitability of nighttime tourism in Kunming is divided into four grades. The most suitable area accounts for 11.83% of the total land area of Kunming, and the highly suitable area accounts for 17.53%. The generally suitable area accounted for 43.29%, and the unsuitable area accounted for 27.35%. The spatial distribution of each grade of suitable areas was obvious. The most suitable areas and highly suitable areas are mainly distributed in areas with dense tourism resources and close to the city center.

Author contributions

Bowen Zhang: Analyzed and interpreted the data; Performed the experiments; Wrote the paper; Man Luo, Jiajia Feng: Contributed reagents, materials, analysis tools or data; Wrote the paper; Zeyu Yi, Lijiang Dong, Qihui Du, Yunfen Yu: Analyzed and interpreted the data; Wrote the paper; Jinping Lin: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

The data that support the findings of this study are openly available in "figshare" at https://doi.org/10.6084/m9.figshare.21687608.v2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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