Chin. Geogra. Sci. 2019 Vol. 29 No. 5 pp. 848–860
https://doi.org/10.1007/s11769-019-1073-8

Springer Science Press
www.springerlink.com/content/1002-0063

# Accessibility Comparison and Spatial Differentiation of Xi'an Scenic Spots with Different Modes Based on Baidu Real-time Travel

WANG Li[1, 2], CAO Xiaoshu[3], LI Tao[3], GAO Xingchuan[1]

(1. *School of Geography and Tourism*, *Shaanxi Normal University*, *Xi'an* 710119, *China*; 2. *Tourism College and Institute of Human Geography*, *Xi'an International Studies University*, *Xi'an* 710128, *China*; 3. *Northwest Land and Resource Research Centre*, *Shaanxi Normal University*, *Xi'an* 710119, *China*)

**Abstract:** A study of the accessibility of a city's scenic spots via different travel modes can contribute to optimization of tourism-related transportation while improving tourists' travel-related satisfaction levels and advancing tourism. We systematically analyzed the accessibility of 56 scenic spots in Xi'an City, China, via car and public transport travel modes using the real-time travel function of the Baidu Maps API (Application Programming Interface) along with spatial analysis methods and the modal accessibility gap index of scenic spots. We obtained the following results. First, maximum and minimum travel times using public transport exceeded those using cars. Moreover, the accessibility of scenic spots via cars and public transport presented a circular spatial pattern of increasing travel time from the center to the periphery. Contrasting with travel by public transport, car travel showed a clear time-space compression effect. Second, accessibility of the scenic spots via cars and public transport showed some spatial heterogeneity, with no clear advantages of car accessibility in the central urban area. However, advantages of car accessibility were increasingly evident moving from the center to the periphery. Third, whereas the correlation of the modal accessibility gap index of scenic spots in Xi'an with global space was significantly positive, local spatial interdependence was only evident in some inner city areas and in marginal areas. Moreover, spatial heterogeneity was evident in two regions but was insignificant in other areas, indicating that the spatial interdependence of the modal accessibility gap index in most scenic spots was not apparent in terms of the overall effect of public transport routes, road networks, and the distribution of scenic spots. The improvement of public transport coverage in marginal areas and the optimization of public transport routes in central urban areas are essential tasks for improving travel using public transport in the future.

**Keywords:** Baidu real-time travel; car accessibility; public transport accessibility; modal accessibility gap; scenic spots; Xi'an City

**Citation:** WANG Li, CAO Xiaoshu, LI Tao, GAO Xingchuan, 2019. Accessibility Comparison and Spatial Differentiation of Xi'an Scenic Spots with Different Modes Based on Baidu Real-time Travel. *Chinese Geographical Science*, 29(5): 848–860. https://doi.org/10.1007/s11769-019-1073-8

## 1 Introduction

Access to convenient transportation is not only a necessary condition for the development of tourism resources and tourist destinations but also an important measure of tourism development within a country or region (Bao and Chu, 2012). Tourism essentially concerns travel. Transportation provides tourists with the mobility to travel to different places, and accessibility is a key index for measuring traffic convenience and enabling tourists to travel. The accessibility of scenic spots is an important aspect of the spatial characteristics of a scenic spot

---

Received date: 2018-09-25; accepted date: 2018-11-20

Foundation item: Under the auspices of National Natural Science Foundation of China (No. 41831284, 41501120), Special Scientific Research Project of Education Department of Shaanxi Provincial Government (No. 18JK0649), Scientific Research Project of Xi'an International Studies University (No. 18XWC24)

Corresponding author: WANG Li. E-mail: rwdlwangli@126.com

(Uchiyama and Kohsaka, 2016) that influences evaluations of their resources, their selection by tourists as destination choices, and tourists' activities at these destinations. A study that explores these issues can advance understanding of an affected area of a scenic spot.

Accessibility was first proposed by Hansen in 1959. It was defined as the potential of interaction (Hansen, 1959), which essentially means the degree of convenience entailed in getting from one place to another (Johnston, 2004). It can also be measured in terms of the time, cost, and effort incurred in travel from the starting point to the destination (Ingram, 1971). Accessibility is widely used within transportation planning, urban planning, and geography and plays an important role in policy making. In recent years, there has been growing scholarly interest in the accessibility of scenic spots. International studies have mainly focused on measuring the accessibility of scenic spots in relation to tourism development. Bifulco and Leone (2014) built an analytical model that they used to compute appropriate accessibility indexes for the Campania region in southern Italy. The constructed model enabled them to determine accessibility to touristic activities within different zones of a touristic region, including cultural heritage, natural assets, swimming, eating and drinking, and leisure as well as their relative importance.

Alkahtani et al. (2015) showed that measurements of the accessibility of scenic spots not only encompass general factors, for example, social population variables and distance but they also include available facilities within scenic spots, scenic spot management, and operational aspects (functions) and mobile infrastructure connecting scenic spots (network connection). Hooper (2015) constructed a tourism accessibility model for Seoul to determine the degree of accessibility of this destination to different types of tourists from various countries, with a particular focus on the impacts of the distance from the destination. Uchiyama and Kohsaka (2016) conducted a survey of Japan's Noto region to examine the cognitive values of different types of tourism resources located at different distances and their relationship to accessibility. The relationship between cognitive value and the accessibility of tourism resources presented a U-shaped curve, with the negative linear function associated with a decreasing relationship and the absence of a clear linear or nonlinear relationship. A study by Gaman and Răcăşan (2016) revealed that the traffic accessibility and development of various Romanian health resorts depends entirely on health factors and on the region's historical environment, with traffic accessibility having little impact on the flow of tourists to Romanian health resorts. Tóth and Dávid (2010) did not find absolute connection between the improvement of accessibility and the increase of incomes. International tourism incomes are far more susceptible to favourable accessibility than domestic ones.

Studies in China have applied different methods for analyzing and measuring the accessibility of scenic spots at different scales and have examined the spatial patterns of their accessibility along with influencing factors and their impacts on tourism. At the national scale, Pan and Li (2014) analyzed the accessibility of 2424 A-grade tourist attractions in China through an examination of their spatial distribution using GIS technology. Their findings clearly revealed traffic directivity. Pan and Cong (2014) developed a classification system for China's tourism at regional levels using the geographical locations and traffic accessibility of scenic spots and based on calculations of the scope of their respective service areas. Cao et al. (2012) conducted a comprehensive study in which they applied data envelopment analysis and the constant elasticity of substitution production function to calculate the internal correlation between the tourism efficiency of national sites of scenic and historical interest and their accessibility. The overall efficiency of tourism increased at a certain threshold level of regional accessibility along with production factors. Jiang et al. (2014) conducted a quantitative analysis of the influence of high-speed railway construction on the accessibility of tourists' places of origin in relation to their destinations at the national scale. Cities and scenic spots located along high-speed railway routes are the main beneficiaries of the network effect of high-speed railway, with high-speed railway services bringing about a time-space compression effect.

At the regional scale, Sun et al. (2017) used a vector road traffic network to measure differences in the accessibility of A-grade scenic spots and star-rated hotels in Hubei Province, China. They found that whereas overall accessibility was good, there were clear regional differences, with accessibility presenting a strong agglomeration pattern. In light of their estimation of the regional accessibility of scenic spots and their hinterlands in the Yangtze River Delta, Jin and Huang (2012) developed a grading system for tourism regionalization. Qin et al. (2015) calculated the accessibility of 123 scenic spots in Xinjiang, categorized at grades AAA and above, using the road resistance function and added factors, such as freight, transportation costs, and actual speeds. In an illustrative case study of the transboundary tourism area of Dabie Mountain, Yang et al. (2013) measured the accessibility of scenic spots influenced by different modes of transportation. Their findings indicated that high-speed and ordinary railway, expressways, and universal transportation had different influences on this tourism area as a whole and on particular parts of it. Guo et al. (2016) examined the characteristics of the passenger flow distribution in the era of high-speed railway and associated changes through a study of changes in the accessibility of tourist attractions in northeastern cities located along high-speed railway routes that have promoted the development of short- term tourism.

At the local scale, Jin et al. (2009) applied the shortest time-path selection algorithm to calculate and analyze accessibility data for tourist attractions in the city of Nanjing in light of the city's highway network structure. Zhang et al. (2015) employed spatial syntax, kernel density estimation, and buffer analysis in a comprehensive study aimed at quantitatively evaluating the accessibility of tourist attractions in Wuhan from the perspectives of global, local, and perceived accessibility.

Existing studies that have entailed calculations of accessibility have mainly focused on road network simulations and real-time traffic travel times. Buffer analysis along with the minimum distance, travel cost, and attractiveness index methods are the primary methods used in studies focusing on road network simulations (Zhong et al., 2011). In recent years, the Baidu intelligent travel service has emerged as a technological tool that provides users with real-time access to traffic and travel information. This includes real-time route planning and navigation of road conditions as well as travel times and route plans for different modes of transportation, such as self-driven cars, public transport (bus and metro), walking, and cycling. The Baidu Map API (Application Programming Interface) automatically collects data on road conditions. Li and Wang (2012) used this API's automatic ranging and time measuring functions to analyze the mechanism and degree of influence of urban low-carbon public transport on the accessibility of tourist attractions. The study's findings indicated that the use of publicly accessible bicycles in urban areas can effectively increase the accessibility of urban tourist attractions. Huang et al. (2018) used the Gaode map API to obtain the shortest transit times for various modes of transportation. They subsequently analyzed the temporal and spatial accessibility of urban parks in the district of Guangzhou Haizhu using the gravity model and a combination of data on transit times and WeChat heat data.

Comparative studies conducted on accessibility gaps relating to different modes of transportation have focused on residents' intra-city travel. In most urban areas of the United States and Europe, cars have better accessibility than public transport (Levinson, 1998; Shen, 2001; Hess, 2005; Kawabata and Shen, 2007; Silva and Pinho, 2010). By contrast, public transport has better accessibility than cars in Hong Kong (Kwok and Yeh, 2004). Salonen and Toivonen (2013), who calculated travel times using cars and public transport in the Greater Helsinki Area, found that differences in the accessibility of the urban center via these two modes of transport were less than differences for the suburbs. Yang et al. (2017), who conducted a study of Guangzhou's accessibility via cars and public transport, similarly found that accessibility was greater in the case of car travel, and the difference in accessibility in the central area was less than it was in the suburbs. Moreover, the distance to the urban public center, the land use mix, and the densities of the resident populations, bus stations, subway stations, and road networks all influenced the modal transport accessibility gaps. Kawabata (2009), who conducted a study of Boston and San Francisco, concluded that most areas in the city center and near railway stations showed a decrease in differences in accessibility while suburban areas located near major highways showed an increase in these differences.

In sum, comprehensive studies have been conducted in China and elsewhere on the accessibility of tourist attractions that have contributed valuable insights on the measurement of scenic spots' accessibility and their spatial patterns. However, most of these studies have focused on the regional scale and on single-way traffic accessibility. Few studies have focused on the urban scale or on multi-modal accessibility and differences relating to urban attractions. A large proportion of travel in tourist city destinations comprises tourists' travel within these destinations. Consequently, promoting green travel through the use of public transport among tourists is an important consideration. At the same time, modal accessibility gaps influence individuals' transportation choice behavior (Burns and Golob, 1976).

Therefore, a study of differences in accessibility using different means of transport in urban areas would yield valuable insights for optimizing traffic networks and enhancing tourists' green travel. Accordingly, considering Xi'an, a popular urban tourist destination, as our case study, we investigated A-grade tourist scenic spots using Baidu intelligent travel service data. Specifically, we applied an accurate path matching time algorithm, GIS spatial analysis, and the scenic spot modal accessibility gap index to analyze differences in space performance relating to the accessibility of scenic spots via cars and public transport. In doing so, we aimed to provide a theoretical basis for the optimization of spatial patterns and modes of traffic related to tourism.

## 2 Study Area and Targeted Scenic Spots

Xi'an is China's most popular touristic city destination with the best international image among Chinese cities. Currently, construction in Xi'an, aimed at creating a first-class international tourist destination and achieving the rank of the 'Oriental Cultural Tourism Capital of the World' is proceeding at a fast pace. In 2016, this city hosted 150 million domestic and overseas tourists, who collectively generated revenue amounting to 120 billion yuan RMB (Yang and Zhang, 2016). In 2017, the number of tourists received in Xi'an reached 180 million, with tourism revenue rising to 163.3 billion yuan (China Industry Information Network, 2018). At present, 11 zones are under Xi'an's jurisdiction: Xincheng, Beilin, Lianhu, Yanta, Weiyang, Baqiao, Yanliang, Lintong, Chang'an, Gaoling, and Huyi. Xixian, which is a new district, is also being administered by Xi'an's authorities. Therefore, we selected all A-grade scenic spots under the jurisdiction of Xi'an as well as those located in the section of Xixian that falls within Xi'an. Thus, the study covered a total of 56 scenic spots, which were primarily historical and cultural sites and natural landscapes (Table 1).

Figure1 shows the locations of the scenic spots. Changan has the largest number of scenic spots (12), followed by the districts of Yanta (10), Huyi (8), Baqiao (6), Lintong (5), Weiyang (4), Beilin, Gaoling, Lianhu, and Xixian New District (2 in each district) while numbers of scenic spots were lowest in the districts of Xincheng, Yanliang, and Beilin/Lianhu (1 in each district). The Xi'an City Wall scenic spot is shared by the districts of Beilin and Lianhu. The 5-A grade scenic spots were confined to Lintong District (2) and Yanta District (1).

**Table 1** Scenic spots of grade A and above in urban area of Xi'an, China in 2018

| No. | Scenic spot | Location | Grade |
|---|---|---|---|
| 1 | Emperor Qinshihuang's Mausoleum (Museum Site) | Lintong District | 5A |
| 2 | Huaqing Palace | Lintong District | 5A |
| 3 | Xi'an Big Wild Goose Pagoda-Tang Paradise Garden Scenic Spot | Yanta District | 5A |
| 4 | Xi'an Beilin Museum | Beilin District | 4A |
| 5 | Shaanxi History Museum | Yanta District | 4A |
| 6 | Xi'an Circumvallation Tourist Attraction | Beilin District/Lianhu District | 4A |
| 7 | Cuihua Mountain Landslide National Park | Chang'an District | 4A |
| 8 | Qujiang Polar Ocean Park | Yanta District | 4A |
| 9 | Shaanxi Tai Ping National Forest Park | Huyi District | 4A |
| 10 | Xi'an Qinling Wildlife Zoo | Chang'an District | 4A |
| 11 | Tang West Market Culture Scenic Area | Lianhu District | 4A |
| 12 | Xi'an Guanzhong Folk Art Museum | Chang'an District | 4A |
| 29 | Xi'an Xiangyu Forest Park | Chang'an District | 3A |
| 30 | Xi'an Changning Palace Leisure Villa | Chang'an District | 3A |
| 31 | Xi'an Guangren Temple | Lianhu District | 3A |
| 32 | Xi'an Yanliang Aviation Science and Technology Museum | Yanliang District | 3A |
| 33 | Yang Hucheng General's Cemetery | Chang'an District | 3A |
| 34 | Xi'an Gaoling Rare Stone Museum | Gaoling District | 3A |
| 35 | Zhongkui Folk Culture Tourism Scenic Spot | Huyi District | 3A |
| 36 | Hu County Mountain Wanhua Chaoyang Scenic Area | Huyi District | 3A |
| 37 | Xi'an Qinglong Temple Site Scenic Area | Yanta District | 3A |
| 38 | Xi'an Daqin Hot Spring Scenic Spot | Weiyang District | 3A |
| 39 | Xi'an Dahan Shanglinyuan (Du Tomb) Ecological Scenic Area | Yanta District | 3A |
| 40 | Baqiao Ecological Wetland Park | Baqiao District | 3A |

Continuing Table

| | Scenic spot | Location | Grade | | Scenic spot | Location | Grade |
|---|---|---|---|---|---|---|---|
| 13 | Xi'an Banpo Museum | Baqiao District | 4A | 41 | Chang'an Mountain Wanhua Scenic Area | Chang'an District | 3A |
| 14 | Xi'an Museum (Small Goose Pagoda) | Baqiao District | 4A | 42 | Feng Dong Feng River Ecological Scenic Area | Xixian New District | 3A |
| 15 | Daming Palace National Herritage Park | Weiyang District | 4A | 43 | Xi'an Bailuyuan Grape Theme Park | Baqiao District | 3A |
| 16 | Xi'an Expo Park | Baqiao District | 4A | 44 | Xi'an Guangxinyuan Ethnic Village | Chang'an District | 3A |
| 17 | Xi'an Hancheng Lake National Tourist Attraction | Weiyang District | 4A | 45 | Xi'an Shiyang Farm Ecological Leisure Tourism Park | Yanta District | 3A |
| 18 | Xi'an Chan Ba National Wetland Park | Weiyang District | 4A | 46 | Xi'an Huanan City Scenic Area | Baqiao District | 3A |
| 19 | Xi'an Fengdong Modern Urban Agriculture Expo Garden | Xixian New District | 4A | 47 | Xi'an Taohuatan Scenic Area | Baqiao District | 3A |
| 20 | Xi'an Golden Dragon Gorge Scenic Spot | Huyi District | 4A | 48 | Xi'an Gaoling Farmside Farming Culture Ecological Tourism Industrial Park | Gaoling District | 3A |
| 21 | Xi'an Zhuque National Forest Park | Huyi District | 4A | 49 | Jia Pingwa Cultural Museum of Art | Lintong District | 3A |
| 22 | Shaanxi Natural Museum | Yanta District | 4A | 50 | Heritage Park of Qin Er Shi Mausoleum | Yanta District | 3A |
| 23 | Caotang Temple | Huyi District | 3A | 51 | Qinling 9-Dragon Pool Tourist Resort | Chang'an District | 2A |
| 24 | Lintong Museum of China | Lintong District | 3A | 52 | Xi'an Lianzhutan Scenic Area | Chang'an District | 2A |
| 25 | China Xi'an Da Xing Shan Temple | Yanta District | 3A | 53 | Jingye Temple Longtan Water Scenic Area | Chang'an District | 2A |
| 26 | Shanxi Qinling Dabagou Scenic Spot | Chang'an District | 3A | 54 | Xi'an Green Leaf Manor | Yanta District | 2A |
| 27 | Hu County Chongyang Palace | Huyi District | 3A | 55 | Yili Group Xi'an Industrial Park | Lintong District | 2A |
| 28 | Eighth Route Army Xi'an Office Memorial Hall | Xincheng District | 3A | 56 | Hu County Jiuhua Mountain Auntie Spring Peony Garden Scenic Area | Huyi District | 2A |

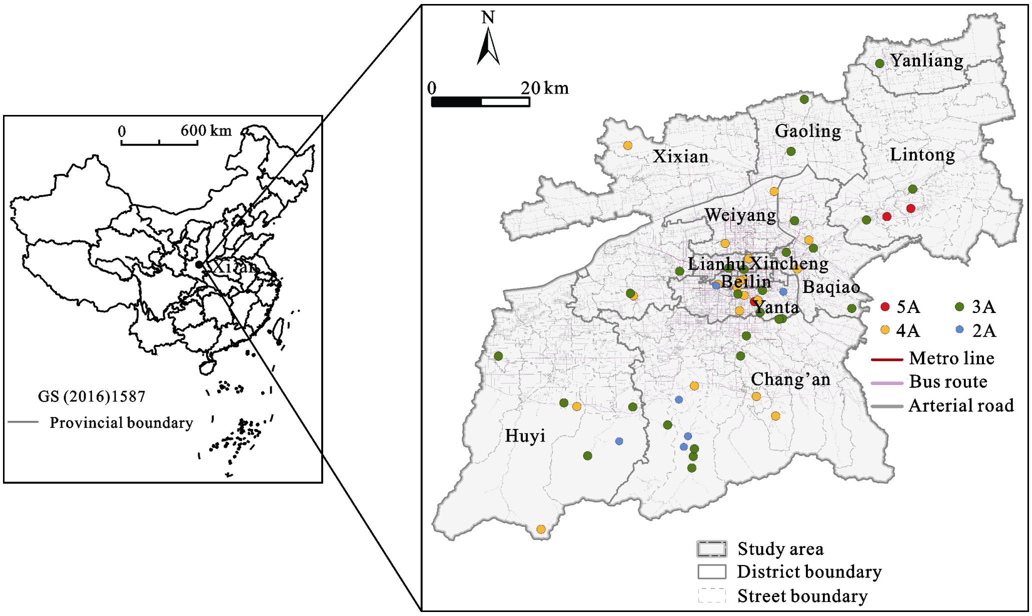

**Fig. 1** Locations of Xi'an City and A-grade scenic spots in urban area of Xi'an, China

Xi'an's road network is shaped like a checkerboard, with a road pattern comprising one high road (an east-west viaduct), one winding road (circling the city), two axial roads (the East-West Fifth Road and the North-South Avenue), and three ring roads (the first, second, and third ring roads). In 2016, the length of the city's road network was 3435 km, covering an area of 79.9 km$^2$. In the same year, there were 7829 public transport vehicles in operation in Xi'an, plying 270 routes covering 6145.6 km (Xi'an Local Chronicle Office, 2017). Further, the city's daily volume of taxi passengers was 1.46 million, with a total number of 12 435 urban taxi units and a daily average of 44 completed cycles. The mileage of rail transit increased to 91 km, with an average daily flow of 1.5 million passengers across the entire network. By the end of 2017, the city's road network density was 5.49 km/km$^2$, ranking 22nd in the country (Xi'an Local Chronicle Office, 2018).

## 3 Data and Methods

### 3.1 Data collection

The vector data used in this study included the administrative boundaries of road and street network of Xi'an. The road network data were collected from the global Open Street Map database for the year 2015, and the remaining vector data were obtained from the Xi'an Planning Bureau. To obtain accurate travel times to the scenic spots, we used the ArcGIS 10.1 software to divide the study area into 8874 grids, each of which also constituted the starting point (O), with each of the 56 scenic spots (depicted as points) being an end point (D). The spatial locations of O and D points were automatically matched by the Baidu API. Accordingly, the respective car and public transport travel times were automatically obtained through the Baidu API's path recognition function obtained for 496 944 O-D pairs. Contrasted with the conventional method used to calculate the passage of time during travel through the road network, the Baidu API is able to account for factors such as the road speed, road congestion, and walking time, thereby eliciting data that are more accurate. The data can reflect the accessibility and gaps for different transport modes more accurately, leading to a reduction of the algorithm error associated with the traditional road network. All data were collected from Monday to Friday of each week day in November 2018. Weekend data were excluded because of the variable traffic conditions.

### 3.2 Accessibility index of different transport modes for the scenic spots

#### *3.2.1 Grid point-scenic spot accessibility*

Grid point-scenic spot accessibility denotes the accessibility of the scenic spot from the grid center points and was calculated using the following equations:

$$A_i^c = \mathrm{Min}(M_j T_{ij}^c) \tag{1}$$

$$A_i^p = \mathrm{Min}(M_j T_{ij}^p) \tag{2}$$

where, $T_{ij}^c$ and $T_{ij}^p$ respectively denote the time taken to reach the scenic spot ($j$) from any point in area ($i$) using cars and public transport as modes of travel; $M_j$ denotes the weight of the scenic spot. Because this study only examined the accessibility of tourist attractions, the weight was set at a value of 1. $A_i^c$ and $A_i^p$ respectively denote the accessibility of scenic spots via cars and public transport used as the modes of travel.

#### *3.2.2 Average accessibility of grid point-scenic spots*

The formulas used for calculating the average accessibility of a grid point-scenic spots, which denotes the average accessibility of a grid point to all scenic spots, were as follows:

$$A^c = \sum_{1}^{n} A_i^c / n \tag{3}$$

$$A^p = \sum_{1}^{n} A_i^p / n \tag{4}$$

where $n$ is the number of scenic spots, and $n = 56$ in this study. $A^c$ and $A^p$ respectively denote the average accessibility of grid point-scenic spots via cars and public transport.

### 3.3 A model of differences in accessibility of scenic spots using different modes of transport

$$TG_{ij} = T_{ij}^p - T_{ij}^c \Big/ T_{ij}^p + T_{ij}^c \tag{5}$$

$$MAG = \sum_{j=1}^{n} TG_{ij} \Big/ n \tag{6}$$

where $TG_{ij}$ denotes the time difference entailed in travel to scenic spot $j$ from any point $i$ within the area by public transport and by car, with values ranging from –1 to

1. If $TG_{ij} = 0$, then the travel times for public transport and car travel are the same. If $-1 < TG_{ij} < 0$, then the travel time for public transport is less than that for car travel, indicating greater accessibility of $j$ via public transport. If $1 > TG_{ij} > 0$, then the travel time using public transport exceeds that using a car, indicating greater accessibility of $j$ using a car as the travel mode. *MAG* denotes the transport modal accessibility gap for the departure point $i$ within the area, with values ranging from –1 to 1. In this study, the starting point $i$ comprised 8874 grid centers. Destination $j$ comprised the 56 A-grade scenic spots, and $n$ denotes the number of destinations.

### 3.4 Spatial autocorrelations of transport modal accessibility gaps in scenic spots

Spatial autocorrelation analyses were performed using Global Space Moran's $I$ and Local Moran's $I$ (Moran, 1948; Anselin, 1995; Lv and Cao, 2010). Global Space Moran's I was used to determine whether there was spatial interdependence and autocorrelation of the modal accessibility gap index in scenic spots of Xi'an.

$$\text{Global Moran's } I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(T_i - \overline{T})(T_j - \overline{T})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}}$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}\left(T_i - \frac{1}{n}\sum_{i=1}^{n} T_i\right)^2 \qquad (7)$$

The $Z$-test was performed to assess the significance of Global Moran's $I$. Local Moran's $I$, which is an indicator of local spatial correlation, was applied to measure whether autocorrelation (the local indicator of spatial association (LISA)) occurred in neighboring spaces. For each basic spatial unit $i$, LISA was calculated as follows:

$$\text{Local Moran's } I_i = \frac{(T_i - \overline{T})}{S^2} \sum_{i,j=1}^{n} W_{ij}(T_j - \overline{T}) \qquad (8)$$

in Eqs. (7) and (8), $n$ denotes the number of spatial units, $T_i$ and $T_j$ are the observed values, and $T$ denotes the average value of $T_i$. $W_{ij}$ denotes the spatial connection matrix of spatial element $i$ and the spatial element $j$ ($i, j = 1, 2, 3, ..., n$) within the scope of the study. The spatial connection matrix used in this study was the adjacency matrix, that is, 1 and 0 represented the adjacent relation between $i$ and $j$, 1 represented the adjacent relation between $i$ and $j$, and 0 represented their non-adjacent relation. $W_{ij} = 0$ constituted the $n$-dimensional matrix $w$ ($n$, $n$). The $Z$-test was performed to assess the significance of Local Moran's $I_i$.

## 4 Results and Discussion

### 4.1 The distribution characteristics and spatial differences of scenic spot accessibility via cars

Seven time periods, entailing 20-min intervals, were defined to measure the accessibility of scenic spots via cars. The spatial distribution and cumulative frequencies for these seven time periods were subsequently calculated (Fig. 2). The accessibility of scenic spots within a period of 80 min via car travel applied to 85.78% of the total area, with a time period of 40 min for accessibility via car travel only applying to 8.01% of the total area. The most widely distributed time period in relation to the spatial distribution frequency was 60 min, accounting for 37.07% of the total area. The second most widely distributed time period was 80 min, which accounted for 30.03% of the total area. The distribution areas that were least accessible via car travel were narrower, with only 0.01% of the total area being accessible by car over 120 min. The area proportions of car accessibility in 0–20, 20–40, 80–100 and 100–120 min were relatively small and their respective differences (3.65%, 9.69%, 12.90%, and 8.42%) were insignificant. For the cumulative frequency, accessibility via car travel increased for a time period of within 120 min and subsequently showed a horizontal trend, indicating that the accessibility of the scenic spot through car travel was mostly within a time period of 120 min. In other words, the average time taken to reach the 56 A-grade scenic spots from any point within the study areas was generally under 120 min. The overall trend for the distribution frequency presented an inverted U-shaped distribution structure. With an increase in time, the distribution frequency first rose and then declined, with the rise occurring more rapidly than the fall. As Fig. 3 shows, there were spatial differences in the accessibility of scenic spots via car travel. The overall trend for the structure of circle layer was that of a gradual increase in the average time of car travel moving from the inside to the outside of the circle. The fastest period of expansion of the traffic circle for cars was 40–80 min, whereas the short circle for cars expanded more slowly in less than 40 min. The most accessible areas for travel by car were Xincheng and Beilin Districts, followed by Yanta District, parts of Baqiao District, which is adjacent to Xincheng District, and then Lianhu District, most of Baqiao District, and the districts of Weiyang, Lintong, Xixian, Changan, and Huyi, with the peripheral region evidencing poor accessibility using cars as the travel mode.

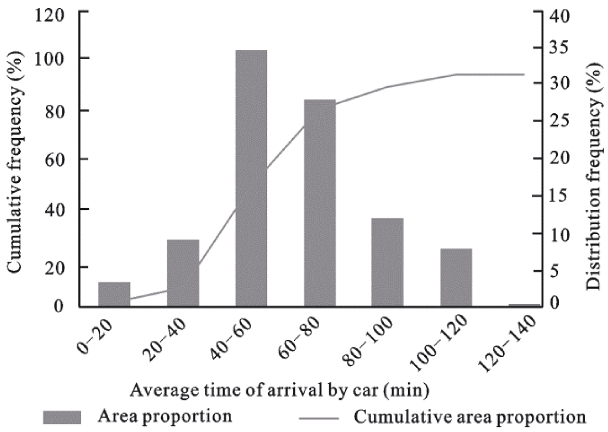

**Fig. 2** The accessibility of scenic spots reached via cars in urban area of Xi'an, China

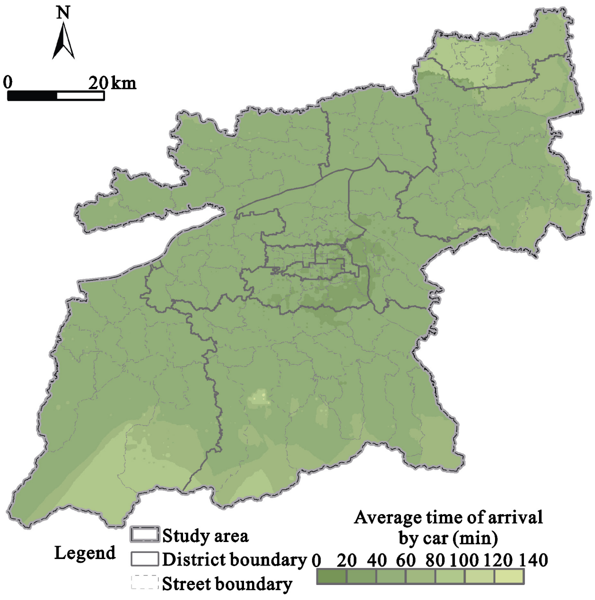

**Fig. 3** The spatial pattern of accessibility of scenic spots via cars in urban area of Xi'an, China

### 4.2 The distribution characteristics and spatial differences in scenic spot accessibility via public transport

The accessibility of scenic spots was categorized into 31 time periods based on 20-min intervals. The spatial distribution and cumulative frequencies were calculated for the 31 time periods. As Fig. 4 shows, 90.52% of the scenic spots were accessible via public transport within 300 min, whereas only 1.64% and 0.29% of the total area were accessible by public transport within 80 and 40 min, respectively. The most extensive spatial distribution frequency for each temporal interval was 140–160 min, which accounted for 12.54% of the total area, followed by a frequency of 120–140 min, accounting for 11.16% of the total area. On the whole, the scenic areas that were accessible via public transport increased gradually, but changes in accessibility were significant. In terms of cumulative frequency, accessibility via public transport increased gradually within a time period of 360 min, subsequently tending to remain horizontal, which implied that the scenic spot was generally accessible via public transport within 360 min. In other words, the time taken to reach the 56 A-grade scenic spots from any point in the study area was mostly within 360 min.

As Fig. 4 shows, the distribution frequency presented an inverted U-shaped distribution structure. With an increase in time, the distribution frequency first rose and then fell, with the increase being greater than the decrease, which fluctuated somewhat. As Fig. 5 shows, the spatial pattern of accessibility via public transport was the same as that for accessibility via cars, revealing a structure of circle layer with reduced accessibility moving from the inside to the outside, and a gradually increase in public transport travel time moving from the center to the periphery. The public transport transit circle of 100–140 min demonstrated the fastest expansion, whereas the public transport short-time circle for other periods expanded more slowly. Accessibility via public transport was relatively better for the following districts: Lianhu; Xincheng; Beilin; Yanta; the western part of Baqiao District, which is adjacent to the inner city area; the southern part of Weiyang District; the northern part of Changan District; and the southeastern part of Xixian New District. The average time taken to reach these areas using public transport was up to 120 min, and the

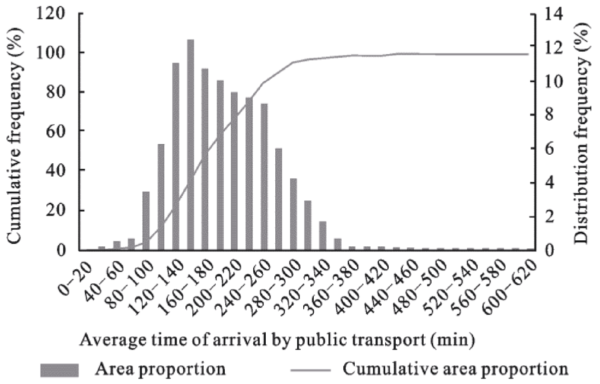

**Fig. 4** Scenic spot accessibility via public transport in urban area of Xi'an, China

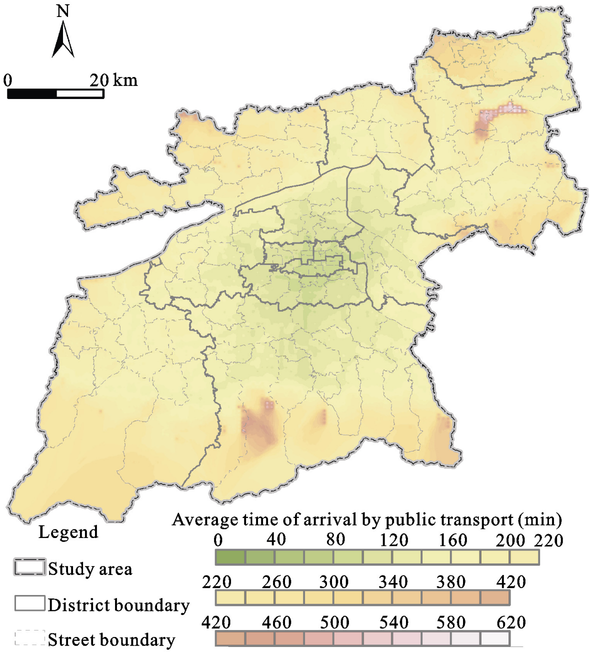

**Fig. 5** The spatial pattern of accessibility of scenic spots via public transport in urban area of Xi'an, China

accessibility distribution structure was one of radial distribution of public transport lines, with areas where public transport lines were densely distributed being more accessible than those where the distribution was less dense. Districts located in the outer periphery, namely Huyi, Chang'an, Lintong, Yanliang, Gaoling, and Xixian New District were the least accessible via public transport, with travel times of over 300 min.

### 4.3 The spatial pattern of modal accessibility gaps in Xi'an's scenic spots

As depicted in Fig. 3 and Fig. 5, the travel times to the scenic areas via cars and public transport were less than those for scenic areas located in the periphery. These figures show that the minimum time (21 min) and the maximum time (600 min) taken to reach a scenic spot via public transport both exceeded the minimum (3 min) and maximum (131 min) times taken to reach it via car travel. The number of hierarchical distribution of public transport travel time in the scenic spot was greater than that for car travel time to the scenic spot, indicating that the overall spatial difference of central and peripheral scenic spot accessibility via public transport was greater than that for car travel to the scenic spot. However, for the same time interval, the area of scenic spots accessible via public transport was much less than the area accessible via cars. For example, for the 100–120 min category, the areas accessible via public transport and cars were 364.77 km$^2$ and 484.44 km$^2$, respectively. The area accessible by car was 1.33 times that of the area accessible via public transport, and the gap between accessibility via cars and public transport for this period was the smallest at the same time intervals.

As shown in Fig. 6 and Fig. 7, the *MAG* value ranged between 0 and 1, indicating that the travel time to scenic spots throughout Xi'an using public transport was greater than the travel time using cars, suggesting that scenic spots were more accessible via cars. Fig. 6 shows the results calculated for the spatial distribution and cumulative frequencies of *MAG* values. The widest distribution of values relating to the spatial distribution frequency of each *MAG* value ranged between 0.45 and 0.50, accounting for 26.69% of the total area. The second widest value distribution ranged between 0.50 and 0.55, accounting for 26.22% of the total area. Scenic areas demonstrating large and small differences in accessibility for different modes of transport accounted for a small proportion of the total area, whereas areas with the largest difference, ranging between 0.60 and 0.65, accounted for 4.62%, and the area with a small difference of 0.25 in *MAG* values accounted for 3.92% of the total area. Most of the area (96.62%) was within a *MAG* value range up to 0.60, and areas with significant differences in accessibility relating to different modes of transport were widely distributed. As depicted in Fig. 6, the distribution frequency presented an inverted U-shaped distribution structure, which first increased and then decreased with an increase of time, with the increase being greater than the decrease. While the structure was essentially a center-edge structure, the spatial layouts of *MAG* values evidently differed. The overall difference in *MAG* values in the southern part of urban Xi'an was less than it was in the north, and the *MAG* value in the central urban area was generally the smallest, distributed within the districts of Lianhu, Xincheng, and Beilin. The *MAG* values were higher in marginal areas in the southwestern part of Huyi District, the southeastern part of Chang'an District, and in parts of Lintong, Yanliang, Gaoling Districts and in Xixian New District, evidencing an increase from 0.0128 to 0.6105. Thus, while there was little difference in the accessibility of scenic areas in central urban areas via public transport and cars, there were significant differences in the accessibility of scenic spots in peripheral areas using these two modes of transport. Therefore, travel using public transport can be considered in central urban areas, whereas car trips are a preferred option for peripheral and marginal areas.

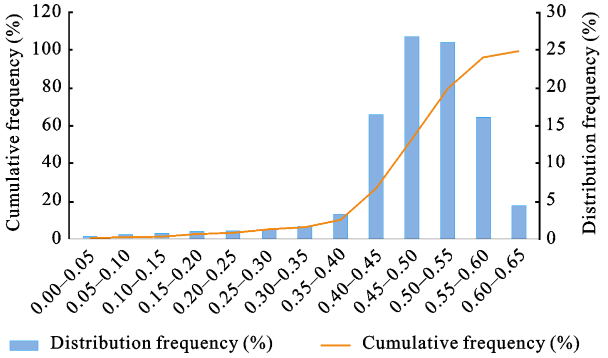

**Fig. 6** Modal accessibility gaps (*MAG*) for scenic spots in urban area of Xi'an, China

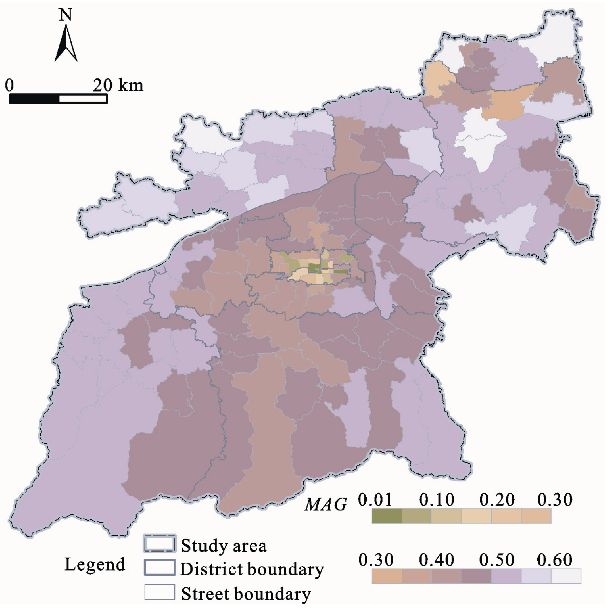

**Fig. 7** The spatial pattern of modal accessibility gaps (*MAG*) in urban area of Xi'an, China

### 4.4 Spatial clustering of the modal accessibility gap index

Figure 8 shows the results of the global autocorrelation analysis. Moran's *I* index was 0.8696, the z-score was 12.2404, and the *P*-value was below 0.005. The modal accessibility gap index for scenic spots in Xi'an evidenced a significant positive global spatial correlation. That is, there were similarities in modal accessibility gaps among the adjacent regions in the spatial distribution. Local autocorrelation analysis, clustering, and outlier analysis were used to identify high and low levels of spatial clustering and spatial outliers and statistically significant differences in the accessibility of scenic spots in Xi'an via different travel modes. High-high value clustering (H-H), low-low value clustering (L-L) and low-high outliers (L-H) were obtained. As shown in Fig. 9, L-L value clustering was mainly distributed in Lianhu, Xincheng, and Beilin Districts while H-H value clustering was mainly distributed in marginal areas of Xi'an, namely the western part of the Xianyang section of Xixian New District, Yanliang District, the northern and southeastern parts of Lintong District, the southeastern part of Chang'an District, and the western part of Huyi District. Abnormal low and high values were obtained for Baqiao District and for part of the Xi'an section of Xixian New District. In other areas, the local spatial autocorrelation of the modal accessibility gap index was not significant.

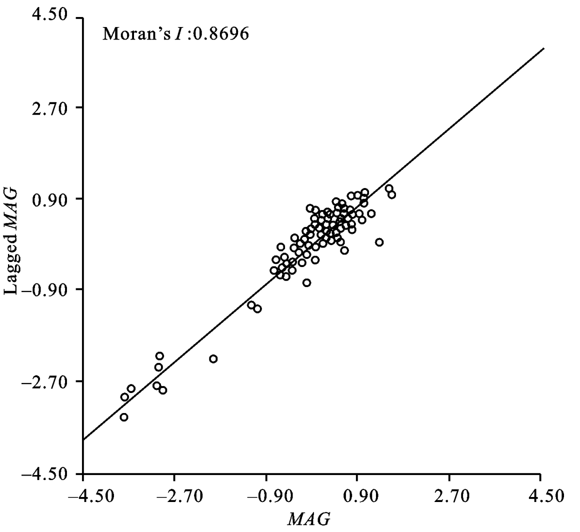

**Fig. 8** A Moran scatter diagram of the modal accessibility gap (*MAG*) index for scenic spots in urban area of Xi'an, China

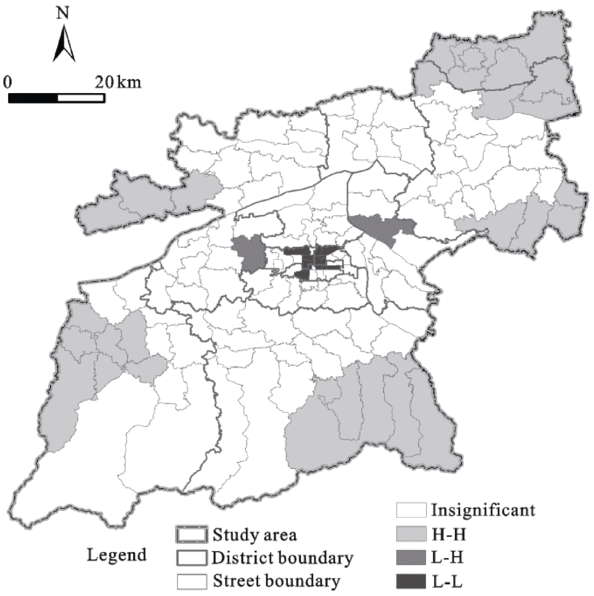

**Fig. 9** Spatial autocorrelation of the modal accessibility gap index for scenic sports in urban area of Xi'an, China. H-H, high-high value clustering; L-L, low-low value clustering; L-H, low-high outliers

## 5 Discussion

A systematic analysis of the accessibility and modal differences of scenic spots in Xi'an was conducted using the real-time travel function of the Baidu Map API in relation to two travel modes: cars and public transport. Accessibility of scenic spots via both cars and public transport evidenced a spatial pattern of increasing travel time from the center to the periphery. Of the total area covered in the study, 85.78% was accessible via cars within an 80-min period, whereas only 1.64% of the total area was accessible via public transport within the same period. Accessibility via public transport in 90.52% of the total area was within 300 minutes. As shown in Fig. 1 and Fig. 3, on the one hand, a limited area was accessible within a short time period via car travel to the scenic spots, mainly because of the large number of scenic spots and their scattered distribution as well as the road network layout and density. On the other hand, the road network layout in the central area, which has a large number of scenic spots, is centralized and dense. Consequently, scenic spots in this central area are relatively accessible via cars, whereas accessibility of sparse scenic spots in remote areas where the road network is limited is relatively poor. As depicted in Fig. 1 and Fig. 5, the spatial distribution pattern of accessibility using public transport has a clear traffic orientation. A denser distribution of public transport routes corresponds to greater accessibility, and the reverse also applies. This finding is consistent with those of previous studies. Accessibility for both modes of transport evidenced a certain degree of spatial heterogeneity, with an increasing trend moving from the center to the periphery and a smaller modal accessibility gap in the southern part of Xi'an than that in the north. Specifically, all of the *MAG* values were greater than 0, indicating that the travel time using public transport exceeded car travel time. This finding is directly related to the different modes of operation; the *MAG* value for the central city was low, indicating that the accessibility of this area via cars and public transport is basically the same. In other words, travel via public transport entails a comparative advantage; because the *MAG* value of the city's periphery is high compared with public transport travel, car travel is more convenient. The spatial distribution shown in Fig. 1 and Fig. 7 reveal that central and peripheral urban areas are covered by contiguous areas entailing similar differences in accessibility, which are closely related to the layout and density of the road network and public transport and to the distribution density of scenic spots. The findings of this comparative study on differences in the accessibility of scenic spots are similar to those of Salonen and Toivonen (2013) and Yang et al (2017) on differences in accessibility among residents. The car travel time is less than the travel time using public transport, with differences in traffic accessibility being less in the central area compared with those in the suburbs. The modal accessibility gap index of scenic spots in Xi'an evidenced a significant global spatial positive correlation, but local spatial interdependence was only evident in some inner city and marginal areas. Two areas demonstrated spatial heterogeneity, which was not significant in other areas, indicating that the spatial interdependence of the modal accessibility gap index of most scenic spots was not conspicuous because of the overall effect of public transport routes, road networks, and the distribution of scenic spots.

## 6 Conclusions

The following conclusions emerge from the above analysis. The accessibility of scenic spots in Xi'an via cars and public transport both showed a structure of circle layer. Compared with public transport, car travel evidenced a clear time-space compression effect. Whereas the accessibility advantages of car travel in the central area were not apparent, they were increasingly evident traveling from the center to the periphery. Given the objective of prioritizing travel via public transport in future planning, attention should focus on increasing public transport routes and site coverage of peripheral areas where public transport is deficient and improving public transport services while maintaining the current level of these services in the central area.

Studies on accessibility relating to different modes of transport will contribute to improving tourism-related travel efficiency. Specifically, studies on modal accessibility gaps will enable spatial differences regarding the most appropriate modes of travel to be evaluated, thereby providing important inputs that contribute to the sustainable development of tourism through the transformation of modes of transport. Explorations of the accessibility of scenic spots via different travel modes in cities that are popular tourist destinations is of great value for optimizing tourism-related transportation, enhancing tourism satisfaction, and promoting tourism development.

The travel times obtained using the Baidu Map API are more accurate than calculations that are based on the traditional road network structure. However, because the actual time for individual travel is not provided, given differences among individual travelers and uncontrollable factors influencing the actual trip, there is still some margin for error, which does not affect the regularity and the results trend. The accessibility of scenic spots facilitates the leisure travel of local residents as well as visits by foreign tourists. However, given constraints in procuring data on residents' settlement patterns and on tourists' spatial distribution within the city, population distribution was not considered in this study of the accessibility of scenic spots. Further in-depth research that integrates resident populations and foreign tourists through the combined use of questionnaires and big data from location-based services (e.g., Weibo) is necessary to enable a more comprehensive exploration of the accessibility of tourist attractions. In addition, although walking was considered as a traffic interchange in the calculation of the accessibility of scenic spots via car travel and public transport, walking and cycling should be considered and analyzed as separate modes of travel in relation to tourists' travel to densely distributed scenic spots in follow-up studies.

## References

AlKahtani S J H, Xia J H, Veenendaaland B et al., 2015. Building a conceptual framework for determining individual differences of accessibility to tourist attractions. *Tourism Management Perspectives*, 16: 28–42. doi: 10.1016/j.tmp.2015.05.002

Anselin L, 1995. Local indicators of spatial association-LISA. *Geographical Analysis*, 27(2): 93–115. doi: 10.1111/j.1538-4632.1995.tb00338.x

Bao Jigang, Chu Yifang, 2012. *Tourism Geography*. 3rd ed. Beijing: Higher Education Press, 329. (in Chinese)

Bifulco G N, Leone S, 2014. Exploiting the accessibility concept for touristic mobility. *Procedia-Social and Behavioral Sciences*, 111: 432–439. doi: 10.1016/j.sbspro.2014.01.076

Burns L D, Golob T F, 1976. The role of accessibility in basic transportation choice behavior. *Transportation*, 5(2): 175–198. doi: 10.1007/BF00167272

Cao Fangdong, Huang Zhenfang, Wu Jiang et al., 2012. The relationship between tourism efficiency measure and location accessibility of Chinese national scenic areas. *Acta Geographica Sinica*, 67(12): 1686–1697. (in Chinese)

China Industry Information Network, 2018. Analysis of tourist market reception and total income in Xi'an of China in 2017. Avalliable at http://www.chyxx.com/industry/201805/639733.html. 2018-05-11. (in Chinese)

Gaman G, Răcăşan B, 2016. Transport accessibility as a factor for tourism flow augmentation. Case study: the Romanian health resorts. *Journal of Settlements and Spatial Planning*, 7(1): 65–77. doi: 10.19188/07JSSP012016

Guo Jianke, Wang Shaobo, Wang Hui et al., 2016. Impact of Harbin-Dalian high-speed railway on the spatial distribution of tourism supply and demand markets in Northeast China cities: based on the accessibility of the scenic spots. *Progress in Geography*, 35(4): 505–514. (in Chinese)

Hansen W G, 1959. How accessibility shapes land use. *Journal of the American Institute of Planners*, 25(2): 73–76. doi: 10.1080/01944365908978307

Hess D B, 2005. Access to employment for adults in poverty in the Buffalo-Niagara region. *Urban Studies*, 42(7): 1177–1200. doi: 10.1080/00420980500121384

Hooper J, 2015. A destination too far? Modelling destination accessibility and distance decay in tourism. *GeoJournal*, 80(1): 33–46. doi: 10.1007/s10708-014-9536-z

Huang Yinghuai, Liu Xiaoping, Liu Yanping et al., 2018. Spatial and temporal accessibility analysis of urban parks based on Amap API by means of multiple transportation: a case study of Haizhu district in Guangzhou. *Geography and Geo-Information Science*, 34(6): 50–57. (in Chinese)

Ingram D R, 1971. The concept of accessibility: a search for an operational form. *Regional Studies*, 5(2): 101–107. doi:

10.1080/09595237100185131

Jiang Haibing, Liu Jianguo, Jiang Jinliang, 2014. An analysis of the accessibility of China's tourist attractions under the impact of high-speed railway. *Tourism Tribune*, 29(7): 58–67. (in Chinese)

Jin Cheng, Lu Yuqi, Zhang Li et al., 2009. An analysis of accessibility of scenic spots based on land traffic network: a case study of Nanjing. *Geographical Research*, 28(1): 246–258. (in Chinese)

Jin Cheng, Huang Zhenfang, 2012. Tourism regionalization in the Yangtze River Delta based on accessibility. *Geographical Research*, 31(4): 745–757. (in Chinese)

Johnston R J, 2004. *The Dictionary of Human Geography*. Chai Yanwei, trans. Beijing: The Commercial Press. (in Chinese)

Kawabata M, Shen Q, 2007. Commuting inequality between cars and public transit: the case of the San Francisco bay area, 1990–2000. *Urban Studies*, 44(9): 1759–1780. doi: 10.1080/00420980701426616

Kawabata M, 2009. Spatiotemporal dimensions of modal accessibility disparity in Boston and San Francisco. *Environment and Planning A: Economy and Space*, 41(1): 183–198. doi: 10.1068/a4068

Kwok R C W, Yeh A G O, 2004. The use of modal accessibility gap as an indicator for sustainable transport development. *Environment and Planning A: Economy and Space*, 36(5): 921–936. doi: 10.1068/a3673

Levinson D M, 1998. Accessibility and the journey to work. *Journal of Transport Geography*, 6(1): 11–21. doi: 10.1016/S0966-6923(97)00036-7

Li Li, Wang Degen, 2012. The impact of urban low-carbon public transport to tourist attractions' accessibility—Suzhou city area as the example. *Economic Geography*, 32(3): 166–172. (in Chinese)

Lv Tao, Cao Youhui, 2010. Construction of spatial autocorrelation method of spatial-temporal proximity and its application: taking regional economic disparity in the Yangtze River Delta as a case study. *Geographical Research*, 29(2): 351–360. (in Chinese)

Moran P A P, 1948. The interpretation of statistical maps. *Journal of the Royal Statistical Society*. *Series B*, 10(2): 243–251.

Pan Jinghu, Cong Yibo, 2014. Tourism regionalization in China based on spatial accessibility of A-grade scenic spots. *Scientia Geographica Sinica*, 34(10): 1161–1168. (in Chinese)

Pan Jinghu, Li Junfeng, 2014. Spatial distribution characteristics and accessibility of A-grade tourist attractions in China. *Journal of Natural Resources*, 29(1): 55–66. (in Chinese)

Qin Wenmin, Zhang Xiaolei, Yang Zhaoping et al., 2015. Accessibility of tourism transport based on link performance function—a case of 3A tourism scenic spots in Xinjiang. *Arid Zone Research*, 32(2): 361–367. (in Chinese)

Salonen M, Toivonen T, 2013. Modelling travel time in urban networks: comparable measures for private car and public transport. *Journal of Transport Geography*, 31: 143–153. doi: 10.1016/j.jtrangeo.2013.06.011

Shen Q, 2001. A spatial analysis of job openings and access in a U.S. metropolitan area. *Journal of the American Planning Association*, 67(1): 53–68. doi: 10.1080/01944360108976355

Silva C, Pinho P, 2010. The structural accessibility layer (SAL): revealing how urban structure constrains travel choice. *Environment and Planning A: Economy and Space*, 42(11): 2735–2752. doi: 10.1068/a42477

Sun Jianwei, Tian Ye, Cui Jiaxing et al., 2017. Identification of tourism spatial structure and measurement of tourism spatial accessibility in Hubei Province. *Economic Geography*, 37(4): 208–217. (in Chinese)

Tóth G, Dávid L, 2010. Tourism and accessibility: an integrated approach. *Applied Geography*, 30(4): 666–677. doi: 10.1016/j.apgeog.2010.01.008

Xi'an Local Chronicle Office, 2017. Xi'an Yearbook (2016). Xi'an: World Publishing Xi'an Co. Ltd. 188−192. (in Chinese)

Xi'an Local Chronicle Office, 2018. Xi'an Yearbook (2017). Xi'an: World Publishing Xi'an Co. Ltd. 189−193. (in Chinese)

Yang Ming, Zhang Rui, 2016. In 2016, The tourism revenue of Xi'an reached 120 billion yuan and tourists reached 150 million. Xi'an News Network. Avaliable at http://www.china.com.cn/travel/txt/2016-12/17/content_39932639.htm. 2016-12-17. (in Chinese)

Uchiyama Y, Kohsaka R, 2016. Cognitive value of tourism resources and their relationship with accessibility: a case of Noto region, Japan. *Tourism Management Perspectives*, 19: 61–68. doi: 10.1016/j.tmp.2016.03.006

Yang W Y, Chen B Y, Cao X S et al., 2017. The spatial characteristics and influencing factors of modal accessibility gaps: a case study for Guangzhou, China. *Journal of Transport Geography*, 60: 21–32. doi: 10.1016/j.jtrangeo.2017.02.005

Yang Xiaozhong, Feng Lixin, Zhang Kai, 2013. The impact of transportation on accessibility of tourism scenic region of cross-border tourism region: a case study of Dabieshan Mountain. *Scientia Geographica Sinica*, 33(6): 693–702. (in Chinese)

Zhang Qi, Xie Shuangyu, Wang Xiaofang et al., 2015. Evaluation on the accessibility of the scenic spots in Wuhan based on the spatial syntax. *Economic Geography*, 35(8): 200–208. (in Chinese)

Zhong Yexi, Liu Ying, Lai Geying, 2011. The study on accessibility and spatial structures for red tourist attractions in Jiangxi province. *Journal of Jiangxi Normal University* (*Natural Science*), 35(2): 208–212. (in Chinese)