

# Spatial Structure of Urban Residents' Leisure Activities: A Case Study of Shenyang, China

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**Abstract:** The spatial characteristics of residents' leisure activities not only reflect their demand for urban leisure space but also affect the urban spatial layout. This study takes Shenyang, China as an example and analyzes the characteristics of residents' leisure activities through questionnaires. On this basis, it uses point of interest data and mobile phone signaling data to identify various types of residential and leisure functional relationships, and uses spatial analysis and community detection to assess the distance characteristics, flow patterns, and community structure of residents' leisure activities, so as to discuss the spatial structure of residents' leisure activities in Shenyang. The results showed that: 1) in addition to leisure at home, Shenyang residents mainly went to shopping malls, supermarkets, and parks for leisure activities, and the proportions of residents of the two types of leisure activities were approximately equal; 2) the average distances that residents traveled for shopping and park leisure were near in the middle and far in the periphery, and the travel costs of peripheral residents for centrally located leisure were higher than those for residents in central areas; 3) the flow patterns of the residential-shopping and residential-park functional relationships displayed clustering mode characteristics, and Shenyang presented a significant monocentric structure; and 4) residents' shopping activities were concentrated in the southern community, and walking in the park activities were concentrated in the western community. Residents' leisure activities were characterized by centripetal agglomeration, which was prone to problems such as traffic congestion and big city diseases. The spatial expansion process in the city was characterized by obvious directional inheritance and path dependence, and the construction of sub-cities is needed to improve the related service facilities.

**Keywords:** leisure activities; travel distance; residential-shopping functional relationship; residential-park functional relationship; community detection

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## 1 Introduction

The five-day workweek was implemented in China in 1995. At present, there are 115 statutory holidays in a year. With leisure time on workdays, more than one-third of a person's time can be spent in leisure (Zhao and Chen, 2010). As residents' living standards improve and life concepts change, the demand for leisure

is increasing among residents, and leisure has gradually become an important lifestyle in modern society. The study of leisure involves the study of leisure time, leisure activities, and leisure space, and the three are closely linked. Leisure time is an important prerequisite for leisure activities and comprises people's time outside of work, sleep, personal time, and housework (Li and Chai, 1999). The hedonic and noncompulsory activities per-

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formed by individuals based on their leisure time are leisure activities (Ragheb and Tate, 1993). Leisure space is an important place for leisure activities. Urban leisure space is where urban residents can engage in various leisure activities, such as entertainment and shopping during their leisure time, and it supports and carries residents' leisure activities, which are closely related to the residents' quality of leisure and life satisfaction (Liu and Zhang, 2013). Urban leisure mainly includes two components: nonlocal tourists to the city to travel and local residents' leisure activities. Notably, leisure travel activities on weekends and holidays involving residents are increasing, and the probability of travel has increased considerably. Thus, this study focuses on the characteristics of the outing-based leisure activities of local residents on weekends and holidays.

Western geographers have conducted a large number of studies on leisure spaces, such as urban parks, green spaces, nature reserves, and seashores (Hall and Petch, 2007), primarily via theoretical review, questionnaire survey, model design and quantitative evaluation, GIS data analysis, and case comparison and explanation methods (Zhu et al., 2011) to study leisure space from the aspects of the spatial structure (Fesenmaier and Lieber, 1987), spatial analysis (Wall et al., 1985), and leisure mode (Song and Jiang, 2014). The analysis of urban leisure includes the following cases. O'Mahony et al. (2009) analyzed the basic situation in Cork Harbor, Ireland, exchanges among different leisure travelers, and the spatial distribution of leisure facilities. Joyce and Sutton (2009) combined the physical, social, and management indicators affecting visitors to rank outdoor recreational areas in New Zealand based on GIS data. Preston-Whyte (2001) studied the coastal leisure space in Durban, South Africa. Western scholars' research on leisure activities primarily includes leisure activity mode (Carr, 1999), leisure activity motivation, and the influence of different individual behaviors on leisure activities (Henderson and Hickerson, 2007). Leisure activities are closely related to leisure space (Johnson and Glover, 2013). Lawson and Manning (2001) analyzed the relationship between the outdoor recreation space and people's wishes to participate in leisure, so as to conduct relevant research on leisure activities and leisure space. Most Chinese scholars who have studied the leisure space of urban residents have focused on three factors. First, the relation between leis-

ure time and residents' leisure space (Tang, 2014) was assessed; specifically, Liu and Chai (2001) applied a temporal geographic method to explore the spatial structure of the leisure activities of Shenzhen residents on weekends based on citizen activity logs. Liu et al. (2018) used public transportation swipe card data to explore the role relationship between the layout of outdoor recreation sites and the outdoor travel behavior of Beijing residents on weekends. Second, the spatial distribution of urban leisure facilities was investigated (Tian and Sha, 2008). Xu et al. (2010) classified the location types and spatial agglomeration characteristics of leisure service facilities in Guangzhou. Third, the characteristics of residents' leisure activities were analyzed. Wu (1994) analyzed the flow trends in the urban recreation for residents in Shanghai. Qin (2003) used questionnaires to analyze the spatial distribution characteristics and trends in urban recreational behavior in Ningbo. Ma et al. (2009) discussed the influential factors and spatial differentiation of residents' shopping travel preferences in different locations and the based on activity logs. Existing studies primarily used survey data, such as resident activity logs and questionnaires, to study the characteristics of urban leisure activities; however, survey data can have issues such as small sample sizes, high costs, and highly subjective results.

With the development and broad application of mobile Internet technology, the generation, recording, and storage of personal data have become part of the daily life of urban residents (Yang et al., 2015). Mobile phone signaling data are the record of information exchanged between mobile phones and base stations when mobile phone users are active in a mobile communication network. These data can reflect the spatial positions of mobile phone users at a certain time and can nearly continuously record the spatial and temporal location changes of living and recreational activities; these data are easy to continuously collect over many days and are convenient for assessing the general characteristics of residents' multiday behaviors (Niu and Ding, 2015). The accuracy of the data is higher, and mobile phone data can effectively reflect people' overall spatiotemporal behavior patterns (Wang et al., 2015) that provide data support for the study of urban residents' leisure activities. The combination of survey data and urban big data enables a better understanding of the spatial characteristics of residents' leisure activities (Liu et al., 2020).

Urban residents' activities show a high degree of regularity associated with urban socioeconomic development and urban spatial characteristics (Song et al., 2010). Understanding the activities of individual urban residents and the group regularity and similarity of their performance is significant to grasping the laws of urban operation and the dynamic evolution of urban space. With the increasingly prominent role and status of leisure activities in people's lives, leisure activities affect the spatial structure and shape of cities (Liu and Chai, 2001).

China's urban development has experienced a stage of rapid expansion. Shenyang, the largest regional center city in Northeast China, has rapidly expanded like other large cities. This paper selects Shenyang as a case city, providing a reference for the study of leisure activity space in other large cities. A questionnaire was used to obtain a preliminary understanding of the characteristics of the leisure activities of Shenyang residents. On this basis, point of interest data and mobile phone signaling data were used to identify the actual leisure activities flows of urban residents and analyze the spatial characteristics of residents' leisure activities. Big data has problems, such as redundancy and processing difficulties, whereas small data has problems, such as low accuracy and limited data volume. The comprehensive use of big data and small data is complementary, and the obtained research results are generally satisfactory and reliable. This study can truly reflect the leisure activity demands of Shenyang residents and provide a scientific basis for improving the organization and layout of urban leisure space and ensuring the quality of life of urban residents.

## 2 Materials and Methods

### 2.1 Study area

Shenyang is the capital city of Liaoning Province. It has a well-developed equipment manufacturing industry and a long history, and was founded more than 2600 years ago. Before the 1990s, because of the technical level and other factors, the Hunhe River became a natural barrier for the southward expansion of Shenyang, creating a long-term lag in the urban development of Hunnan District. However, the development of damming-related techniques and technology and the formal establishment of the Hunnan District in 2001 led the city to

adopt the strategy of 'Big Hunnan, New Shenyang', which led to an expansion across the Hunhe River as an essential step in the city's development. This strategy focused on constructing the Hunnan District and creating an urban spatial structure that can be characterized as 'one city, two districts' in relation to the old urban district.

This study selected central urban area of Shenyang as the research scope, including the following nine administrative subdivisions: Shenhe District, Heping District, Huanggu District, Dadong District, Tiexi District, Hunnan District, Yuhong District, Shenbei New District, and Sujiatun District (Fig.1). The study area includes 96 streets and has a total area of 1254.88 km<sup>2</sup>.

### 2.2 Data source

The questionnaire on the 'leisure activities of residents in Shenyang' was distributed through 'Questionnaire Star' (<https://www.wjx.cn/>) from September 15 to September 27, 2020. The content of the questionnaire mainly included six questions on basic personal information and 16 questions on leisure modes, leisure places, and leisure travel modes at different times on weekdays, weekends, and holidays. Because the surveyed population is Shenyang residents, the completed questionnaire

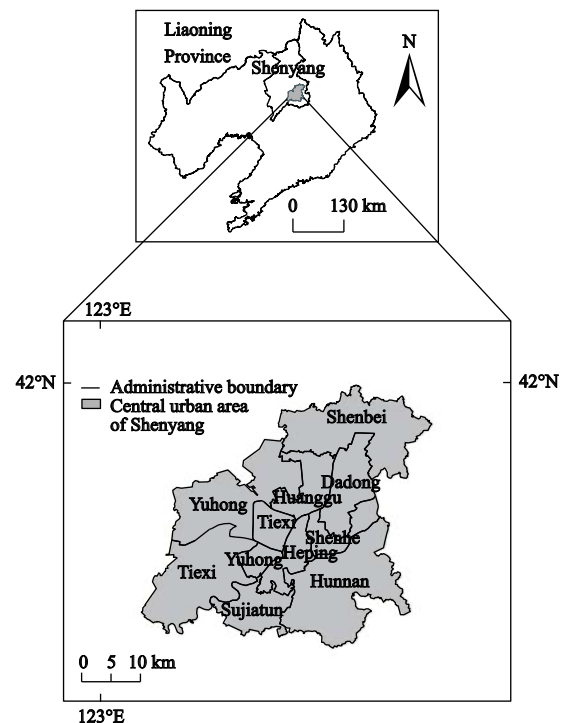


Fig. 1 Location of central area of Shenyang City

is determined to be valid if the IP address of the collected questionnaire is in Shenyang. The final number of completed questionnaires was 746, with 521 valid questionnaires from IP addresses in Shenyang.

Point of interest data were derived from Autonavi Maps (Amap) (<http://www.amap.com>) for Shenyang in 2018 and projected with WGS 84: 1903 shopping leisure facilities and 232 park and green space facilities were identified.

Mobile phone signaling data were derived from Unicom users in Shenyang for May 2018 ([www.smartsteps.com](http://www.smartsteps.com)). After desensitization, all data privacy issues were eliminated. A total of 5374 grids at the scale of 500 m × 500 m were created in the study area for recording and follow-up research. The acquired data included the grid number, number of people within each grid square, longitude and latitude of each grid, and so on. According to the online weather forecast query ([www.tianqihoubao.com/lishi/shenyang.html](http://www.tianqihoubao.com/lishi/shenyang.html)), in May 2018, the average daily low temperature in Shenyang was 12°C, the average daily high temperature was 24°C, and the daily average temperature was 18°C; additionally, sunny and cloudy weather occurred on 90% of the days in the study period. Thus, the study period had suitable weather for mobile phone users to engage in outdoor activities. Mobile phone signaling data cannot directly clarify the purpose of mobile phone users' activities. By considering general living and leisure trends, recognition rules were established for mobile phone user activities.

To measure the resident population, we adopted the following rules. First, we identified the residential observation period as lasting between 21:00 and 8:00 the next day (that is, when users were in one place for this period they were assumed to be at home). Second, we summed users' total amount of time spent in given locations between these hours on a monthly basis and assumed that the location with the highest amount of time spent was their place of residence. Third, the number of days in a month exceeds two weeks (that is, where it was considered to be inhabited by local residents). To measure and conceptualize places of leisure, we observed users' positions when they stayed more than one hour in nonresidential and nonworking grids on weekends and holidays.

The residential-leisure functional relationship was characterized by the number of spatial movements of

residents from a residence to a leisure location; this relation was directional and deemed the residential-leisure origin-destination relationship or the residential-leisure flow. To eliminate errors caused by accidental factors, only travel records from residential places to leisure places in Shenyang for more than two residents were selected. By descriptive statistical analysis in SPSS, it was found that the median number of residents was five. In order to ensure the true and accurate reflection of the general characteristics of residents' leisure activities, a total of 179 225 records with more than four inhabitants reflecting travel from residential places to leisure places in Shenyang were extracted.

## 2.3 Research methods

### 2.3.1 Mathematical and statistical methods

A descriptive statistical analysis of the collected questionnaire data was carried out using SPSS software, and the characteristics of the types of leisure activities, leisure space, and leisure time of Shenyang residents were obtained. The questionnaire questions had single-choice and multiple-choice options, and the percentages of the multiple-choice options equaled the number of times each option was selected divided by the number of valid answers included in the study.

### 2.3.2 Flow pattern recognition

Flow is composed of origin (i.e., residential nodes), destination (i.e., leisure nodes), and its connection attribute. The flow pattern mode can be divided into three types: random, clustering, and aggregation and dispersion modes. The random mode means that the origin and destination of the flow are randomly distributed. The clustering mode can be defined as the aggregation of the flow in the flow space, which is manifested as the simultaneous aggregation of the origin and destination. The aggregation and dispersion modes include the convergence and divergence modes, with the convergence mode defined as the destination clustering of the flow and the dispersion mode as the origin clustering of the flow (Pei et al., 2020). The flow patterns of residential-leisure functional relationships reflect the spatial mobility characteristics and commonalities of residents' actual leisure activities and the relationship between the geographic locations of residential and leisure facilities.

Moran's Index is used as a statistic to measure the degree of agglomeration of spatial points, which measures

the relationship between the attribute values of adjacent spatially distributed objects. The value range of Moran's Index is  $[-1, 1]$ . A positive value indicates that the attribute value distribution of the spatial object has a positive correlation, and a negative value indicates that the attribute value distribution of the spatial object has a negative correlation. The absolute value of this index indicates the autocorrelation intensity, and a value of 0 indicates that no spatial correlation exists; thus, the attribute value of the spatial object is spatially randomly distributed (Anselin, 1988). The corresponding formula is as follows:

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (X_i - \bar{X})^2}$$

In the formula,  $n$  is the number of grids in the region;  $X_i$  and  $X_j$  are the numbers of people living in or involved in leisure in grids  $i$  and  $j$ , respectively;  $\bar{X}$  is the average number of people living in or involved in leisure in the grids; and  $W_{ij}$  is the spatial weight matrix.

### 2.3.3 Community detection

Community detection divides nodes into several communities according to the relationship among the nodes in a network (Girvan and Newman, 2002). A community is formed using a cohesive subgraph of network nodes and many connections exist among nodes in the subgraph; connections among nodes in different subgraphs are relatively rare (Gan et al., 2009). A higher number of internal links that exceed the number of inter-community links indicates a more obvious community structure of the network. Common methods of community detection include modularity (Newman and Girvan, 2004), random walk, and betweenness-based (Qin et al., 2017) methods. In this study, a rapid heuristic computational method using modular optimization in Gephi software was used to divide communities (Blondel et al., 2008). The measurement of modularity is expressed as follows:

$$Q = \sum_{s=1}^{n_c} \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$$

In the formula,  $n_c$  is the number of communities,  $L$  is the total number of connections in the network,  $l_s$  is the number of internal connections in community  $s$ , and  $d_s$  is the sum of all node degrees in community  $s$ .

## 3 Results

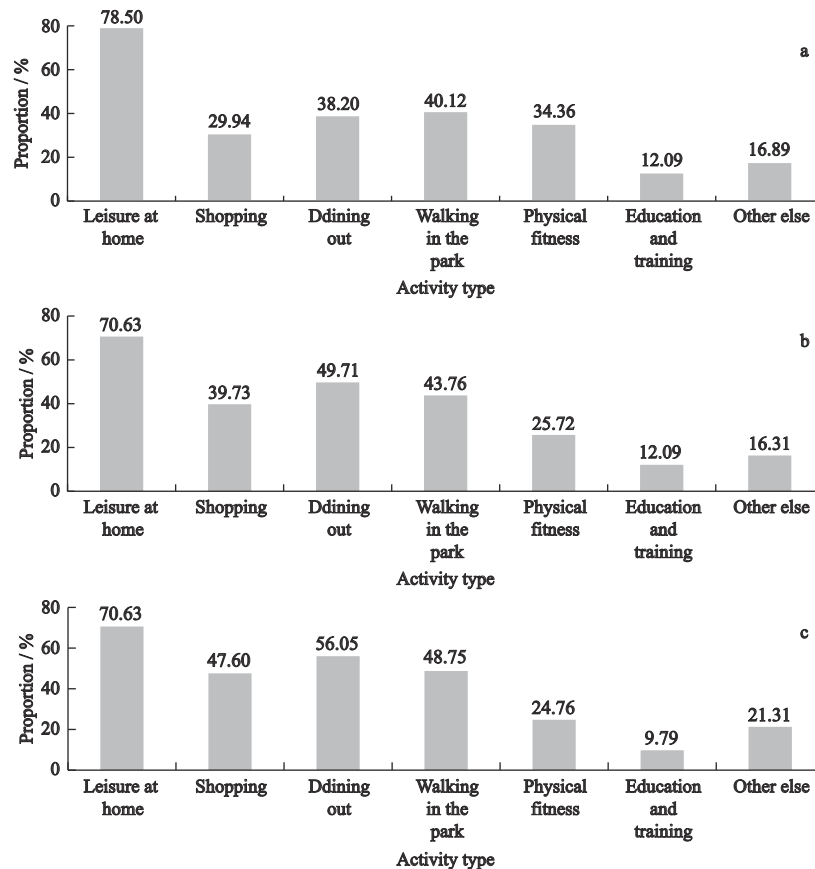
### 3.1 Residents' willingness and characteristics of leisure travel in Shenyang

Among the 521 valid questionnaires, the respondents covered all age groups, occupations, and administrative districts in Shenyang, and the proportion of females was slightly higher, with males accounting for 42.8% and females 57.2%. The characteristics of the leisure activities of Shenyang residents can be obtained for different periods, including workdays, weekends, and holidays (Fig. 2).

The proportion of Shenyang residents choosing leisure activities at home, such as watching TV, surfing the Internet, and reading books, was the highest in the three periods of working days, weekends, and holidays. Among them, 78.50% of residents carried out leisure activities at home on weekdays and 70.63% on weekends and holidays, reflecting that leisure at home was the first choice for urban residents to relax and entertain in their leisure time. Leisure time affected the choice of leisure activities. Compared with weekdays, residents were more willing to engage in outdoor leisure activities on weekends and holidays. The popularity of different types of outdoor leisure activities on weekdays, weekends, and holidays varied, with urban residents preferring to walk in the park on weekdays, followed by dining out and physical fitness, respectively. On weekends and holidays, the first choice of outdoor leisure activities for urban residents was dining out, and the proportion of residents who chose to walk in the park and go shopping was slightly lower. The proportion of residents who chose to dine out, walk in the park, and shop on holidays was higher than that on weekends. With the increase of residents' leisure time, the popularity of these three types of outdoor leisure activities trended upward. On weekdays, the proportion of residents walking in the park was higher, and the residents were more willing to dine out on weekends and holidays, indicating that residents tended to engage in outdoor leisure activities for relaxation and self-improvement on weekdays, whereas residents tended to engage in outdoor leisure activities for socialization and pleasure on weekends and holidays.

Leisure space is the place for leisure activities. Houses, shopping malls, supermarkets, parks, squares, and restaurants were the main leisure spaces for





**Fig. 2** Characteristics of leisure activities of Shenyang residents during different periods. a. Weekdays; b. Weekends; c. Holidays

Shenyang residents. Shenyang residents' leisure time on weekends and holidays was primarily longer than 3 h, whereas their leisure time on weekdays was divided into longer than 3 h and 1–2 h. Shenyang residents mainly chose private cars and public transportation, such as buses or subways, for outdoor leisure activities. When going out for leisure activities, 48.46% of residents were willing to spend 0.5–1 h to reach leisure locations, and 22.88% of the residents who participated in leisure activities traveled for more than 1 h, reflecting that leisure places with high accessibility were more attractive to residents.

### 3.2 Residents' characteristics regarding leisure travel distance in Shenyang

An analysis of the questionnaire survey found that the proportion of Shenyang residents choosing shopping malls and supermarkets, parks, and green spaces for outdoor leisure activities on weekends and holidays was relatively close. According to different travel purposes, 1903 shopping leisure facilities and 232 parks and green space facilities obtained from the point of interest data

set can be combined to subdivide the residential-leisure functional relationship identified by mobile phone signaling data into two types: residential-shopping functional relationship and residential-park functional relationship. In the 5374 grids with dimensions of 500 m × 500 m, the residential-shopping functional relationship was the measured flow of residents starting from 2267 residential nodes and traveling to 666 shopping leisure nodes for shopping leisure activities. The number of connections between residences and shopping leisure locations was 127 375, and the number of residents who traveled from their residence for shopping leisure activities was 773 711. The residential-park functional relationship was the measured flow of residents starting from 1768 residential nodes and traveling to 133 park leisure nodes for park leisure activities. The number of connections between residences and park leisure locations was 25 072, and the number of residents who traveled from their residence for park leisure activities was 104 709. According to the travel distance (i.e., the Euclidean distance) of residents from residential nodes to different types of leisure nodes, it is helpful to ana-

lyze the convenience and difficulty of residents from different residential nodes to obtain leisure functions.

For shopping leisure, the shortest distance traveled was 500 m, the longest distance traveled was 36 554.75 m, and the average distance traveled was 5652.42 m. For park leisure, the shortest distance traveled was 500 m, the longest distance traveled was 34 354.77 m, and the average traveled distance was 5757.27 m. Given the small number of park nodes, the average distance of park leisure activities was larger, and the overall distance of leisure travel from residents to parks was longer. Residents were more willing to travel longer distances for shopping leisure activities than for park leisure activities, and the longest distance traveled to parks was shorter than that for shopping. The average distance of leisure travel was divided into three categories, namely, near, middle, and far, on the basis of the Jenks natural break method, and the average distances to both shopping and park leisure displayed the spatial characteristics of near in the middle and far in the periphery of the study area (Fig. 3). The leisure facilities in the central part of the city displayed the characteristics of strong agglomeration and functional diversity. The number and scale of shopping leisure facilities were dominant. Residents living in the middle of the city had a shorter average travel distance to access shopping leisure than did other residents due to their geographical proximity to multiple commercial and leisure centers. Areas along Daoyi Street, Hushitai Street, and Huishan Street in Shenbei New District; Baita Street and Taoxian Street in Hunnan District; Huxi Street in Sujiatun District; and Dapan Street and Zhajijia Street in Tiexi District are far

from commercial centers. The peripheral north and south areas are mainly equipped with small-scale convenient shopping facilities to serve urban residents in the surrounding areas. A few residents in peripheral areas can access shopping leisure within a short distance, but many residents must travel a long distance for high-quality leisure. On weekends and holidays, various business districts in the central area have problems, such as traffic congestion and limited parking. The average distances traveled for park leisure travel by residents in the middle of the city and along the north and south banks of the Hunhe River belt were relatively shorter. The average distance of park leisure travel for residents in peripheral areas was comparatively longer, suggesting that the spatial layout of park facilities also had the characteristics of central clustering. The number of park facilities on both sides of the Hunhe River was large, and the average distance that residents traveled along the Hunhe River belt to the park leisure facilities was relatively short, making park leisure travel convenient for the surrounding residents.

### 3.3 Pattern recognition for different types of residential-leisure functional relationships in Shenyang

The discussion of the spatial distribution characteristics of the origin and the destination identified the flow patterns of different types of residential-leisure functional relationships. Shenyang residents were involved in shopping leisure activities at 2267 residential nodes and park leisure activities at 1768 residential nodes. Spatial autocorrelation research on the origin of the different types of functional relationship flows enabled the ana-

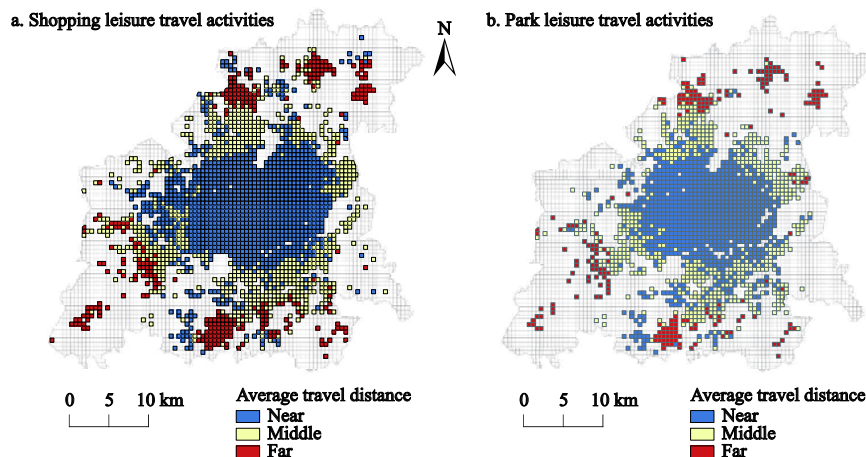


Fig. 3 Average travel distance characteristics of residents' leisure activities in Shenyang, China

lysis of the spatial distribution pattern of the residential nodes. The Moran's  $I$  value of residential nodes associated with the residential-shopping functional relationship was 0.662, with  $P < 0.01$  and  $Z = 185.259$ , and the Moran's  $I$  value of residential nodes associated with the residential-park functional relationship was 0.553, with  $P < 0.01$  and  $Z = 123.436$ . The residential nodes included in the residential-shopping and residential-park functional relationships showed significant positive spatial correlations. The spatial distribution of residential nodes displayed a significant agglomeration feature, indicating that urban residents who go out for leisure activities had strong spatial proximity. Differences existed in the degree of agglomeration of residential nodes corresponding to these two types of leisure activities, where the spatial agglomeration of residents engaged in shopping activities was stronger and the spatial agglomeration of residents engaged in park leisure activities was weaker, reflecting residents' larger spatial distribution range when engaging in park leisure activities.

Shenyang residents were engaged in shopping leisure activities at 666 shopping nodes and park leisure activities at 133 park leisure nodes. The spatial distribution pattern of the leisure nodes was analyzed using spatial autocorrelation research on the destination of different types of functional relationships. The Moran's  $I$  value of leisure nodes associated with the residential-shopping functional relationship was 0.393, with  $P < 0.01$  and  $Z = 51.772$ , and the Moran's  $I$  value of leisure nodes associated with the residential-park functional relationship was 0.233, with  $P < 0.01$  and  $Z = 10.394$ . The leisure nodes of these two functional relationships showed a significant positive spatial correlations, and the spatial distribution of leisure nodes displayed a significant agglomeration feature. Differences existed in the spatial agglomeration of shopping and park nodes. Notably, shopping nodes exhibited a strong spatial agglomeration, and park nodes displayed a weak spatial agglomeration, indicating that shopping activities had a strong degree of agglomeration, whereas park leisure activities had a weak degree of agglomeration. Shopping activities were more likely to generate a dense flow of people and thus more strongly affect urban traffic. A comprehensive analysis indicated that the origins and destinations of residential-shopping and residential-park functional relationships were spatial agglomeration distribution, and the flow distribution patterns were clustering

mode (Fig. 4). Residents' leisure activity space displayed an aggregation trend, reflecting that the single-center structure in Shenyang is more mature.

### 3.4 Community structure of different types of residential-leisure networks in Shenyang

#### 3.4.1 Community structure of residential-shopping leisure network

According to the functional relationship between residences and shopping leisure in Shenyang, a residential-shopping network with  $2267 \times 666$  nodes, 127 375 edges, and 773 711 weights (i.e., residents) was constructed. It was found that if the nodes with close ties were divided into a community, the degree of node connections within the community was stronger than that between communities, and the spatial layout of the nodes in the same community was not completely regular. The number of communities in the residential-shopping network was 4, the modularity was 0.218, and the spatial distribution characteristics of communities were obtained (Fig. 5). Three communities in the network had a strong spatial distribution regularity, and one community had a weak spatial distribution regularity. In the central part of the city, the residential-shopping network was divided by Taiyuan Street, Xita Street, and Jihong Street in Tiexi District, forming a 'fan-shaped' distribution with three communities in the north, west, and south. In the northern community, the North Station and Middle Street-Little East Road area formed the center of commerce and trade, mainly serving residents in the north. The western community included the Xingong business district within Xingong Street, Xinghua Street, and Guihe Street in Tiexi District as the center that served residents in the west. In the southern community, Taiyuan Street and the Wulihe business district formed

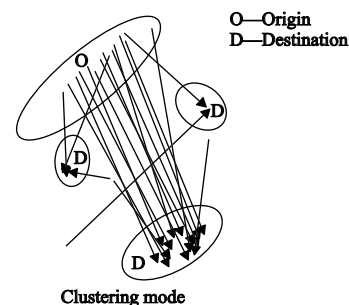
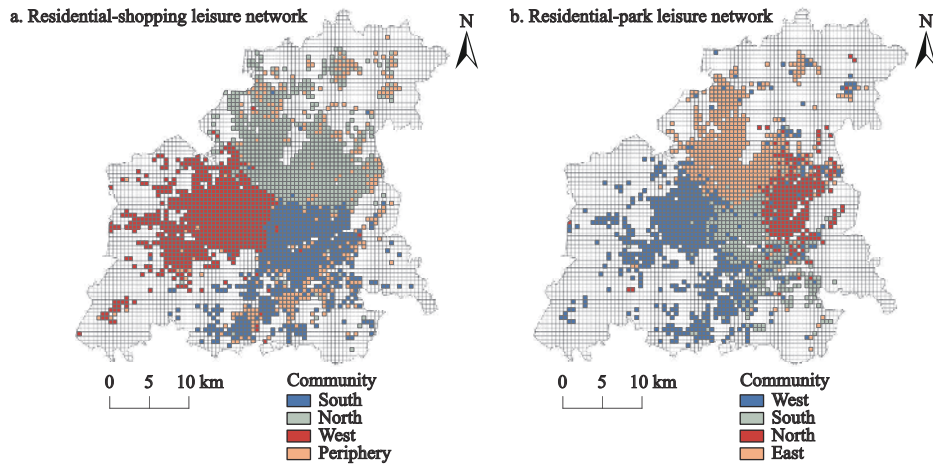


Fig. 4 Clustering mode of residential-leisure function relationship





**Fig. 5** Spatial structures of different types of residential-leisure networks' community detection

a center to serve residents in the south. The community structure of the residential-shopping network indicated that residents' shopping activities were characterized by centripetal agglomeration, and the shopping facilities in the central region were highly attractive to residents. One community had a weak spatial distribution in the peripheral areas scattered in the southern and northern regions. To obtain a high-quality shopping experience, residents in the periphery need a long-distance travel and time-consuming cost.

The functional relationships among the three communities in the north, west, and south with strong spatial laws were as follows (Table 1). The shopping leisure facilities in the southern community mainly included traditional and large-scale commercial centers. The shopping leisure facilities in the northern communities mainly included various types of commercial complexes, where as the shopping leisure facilities in the western communities mainly fell within the home furnishing and home decoration categories, and some complexes were present. Different communities have different degrees of appeal to residents in other communities in the context of satisfying shopping leisure needs of residents in the region. The focus of residents' leisure activities was concentrated in the southern community, and both the northern community and western community had a higher flow of residents to the southern community for shopping. The northern and southern communities were more closely connected to each other, and a large number of residents engaged in cross-regional shopping activities. The traffic in the north-south direction of the city was relatively busy. The shopping leisure facilities in the northern community

were also strongly attractive to residents in the western community. The average distance from other communities to the western community for leisure shopping was relatively far. The shopping facilities in the western community were mainly related to home furnishings and decorations, and a limited number of residents needed these specific shop types. Thus, the community had limited cross-regional appeal to residents in other communities.

**3.4.2 Community structure of residential-park leisure network**

According to the functional relationship between residences and park leisure in Shenyang, a residential-park network with  $1768 \times 133$  nodes, 25 072 edges, and 104 709 weights was constructed. The number of communities in the residential-park network was 4, the modularity was 0.256, and the spatial distribution characteristics of communities were obtained (Fig. 5). With Bajing Street, Xita Street, and Guihe Street in Tiexi District as the boundaries, the region was divided into a 'diamond-shaped' distribution with four communities in the east, south, west, and north. Residents' park leisure

**Table 1** Connections among communities in residential-shopping leisure network

Connections between communities	Number of connections	Number of residents	Average distance (m)
North-west	7731	45621	7334.6
West-north	8253	51428.5	7316.8
North-south	11746	67709.5	7060.9
South-north	7988	52143.5	6031.4
West-south	7913	46012.5	3099.1
South-west	4928	29077	6376

activities were associated with different travel ranges, and park and green spaces generally served nearby urban residents. A certain distance existed between the eastern and western communities, indicating that the spatial agglomeration of park facilities in the east-west direction of Shenyang was weak. The park facilities in the western community were rich in terms of type and content, with notable advantages in scale, thus attracting residents from long distances and covering a large service range. The number of park facilities in the eastern community was limited, and the number of surrounding residents was limited; these parks mainly served nearby urban residents, and the service scope was small. The Qipan Mountain landscape on the northeast periphery was strongly attractive to residents as a gathering area for park leisure activities. When the scale of park leisure places is large, residents choose to visit high-quality parks for leisure activities on weekends and holidays, no matter the distance.

The functional relationships among the four communities in the east, south, west, and north were shown as follows (Table 2). The western community had a high level of attraction, and residents in other communities traveled to obtain park leisure functions with higher flows and smaller average distances in the western community, reflecting that the park facilities of the western community had a greater capacity to accommodate urban residents. Among residents in all the communities, residents in the northern community most frequently visited park facilities in the western community, and the interactions between the northern and western communities were relatively strong. The connective gap between the eastern and western communities was the largest; that is, the flow of people from the eastern community to the western community for park leisure was more than two times that of residents from the western to the eastern community for park leisure. Residents in the western community had the longest average distance to the eastern community to engage in park leisure activities, indicating that park facilities in the eastern and western communities had significant differences in attractiveness to residents and that the connection between the eastern and western communities was weak. Residents in the eastern community for park leisure activities from the other three communities, especially to the northern community, was more than that the other three communities received park leisure activ-

**Table 2** Connections among communities in residential-park leisure network

Connections between communities	Number of connections	Number of residents	Average distance (m)
North-east	681	2525.5	6418.7
East-north	1054	4524	6156.6
North-west	1616	6411	7621.1
West-north	1504	5982	7742.5
North-south	926	4002	8845.9
South-north	1329	5544.5	6021.5
East-west	705	2995	8564.5
West-east	311	1123	9398.9
East-south	883	3879.5	5496.4
South-east	770	2994.5	4529.7
West-south	978	4344	7601.8
South-west	1510	5931	5108.4

ities from the eastern community, which reflected that the number and scale of parks in the eastern community were limited, and it was less attractive to residents in other communities. The number of residents who traveled from the southern community to the western and northern communities to participate in leisure activities in parks was high. The number of residents traveling from the southern community to the western community for park leisure activities was larger, and the average distance was the shortest observed in this analysis. Residents in the southern community were commonly willing to go to the western community to engage in park leisure functions.

## 4 Discussion and Conclusions

### 4.1 Discussion

With the transformation of residents' lifestyles, the demand for residents' leisure function is increasing. Measuring the characteristics of urban residents' actual leisure activities and their spatial structure is one of the key issues in studies of urban spatial structure. Many studies analyzed the characteristics of leisure activities only using data from questionnaires and activity logs or explored the spatial structure of leisure facilities through spatial analysis methods, ignoring the spatial structure characteristics of residents' actual leisure activities.

Based on the theory of behavioral geography, this paper identifies the spatial and temporal location changes of urban residents' multiday leisure activities and the

spatial characteristics of their activities through mobile phone signaling data, and understands urban space on the basis of human behavioral activities, which enriches the research perspective and scale of urban leisure spatial structure to a certain extent, and also enriches the relevant practice of behavioral geography. Taking Shenyang as an example, with the help of network analysis methods, such as traffic pattern recognition and community detection, this paper divided urban functional areas, and excavated the influence of residents' actual leisure activities on urban traffic function and urban spatial structure. The distance and agglomeration characteristics of the leisure activities of Shenyang residents fully reflect the general law of leisure activities of single-center urban residents, which can enlighten studies of the spatial structure and functional relationship of single-center cities. This paper has important reference value for other large cities that have experienced the expansion stage to realize the goal of human-centered, healthy, and orderly city development.

Shopping in malls and walking in parks are two important ways for Shenyang residents to engage in leisure activities, and the demand for supermarkets and green park space is high. Leisure spaces, such as urban commercial centers and various types of large parks, are associated with dense flows of people on weekends and holidays. Compared with park leisure activities, shopping activities attract a larger flow of people and greatly influence the traffic within Shenyang on weekends and holidays. The shopping activities in the northern and southern regions are closely linked, and traffic congestion in the north-south direction deserves further attention and control. The central part of the city has a number of commercial centers, and residents' shopping activities have the characteristics of centripetal agglomeration. The cost of obtaining high-quality leisure functions for peripheral residents is relatively high, which affects urban transportation and urban operational efficiency. The central core region of Shenyang had a strong polarizing effect, and the development of a single urban center had strong inertia and path dependence, making the development of sub-cities difficult.

The following suggestions are offered to ensure the quality of life of urban residents, optimize leisure facilities and urban spatial structures, and improve urban operation efficiency. First, to meet the residents' demand for outdoor leisure activities, the quality and adequate

supply of leisure functions such as parks, green areas, gyms, and supermarkets need to be focus on. Second, factors such as service radius and accessibility make it necessary to appropriately configure shopping and park leisure facilities around residential areas and transportation hubs, and traffic management in the north-south direction on weekends and holidays should be strengthened. Third, ensuring the orderly development of the central city and avoiding disorderly spreading are of great significance in the construction of the four subsidiary cities of Puhe, Yongan, Tiexi, and Hunhe and in the successful realization of a reasonable spatial structure for 'one main city and four sub-cities' in the central city of Shenyang. The construction of transportation hubs and complexes can be a way to realize the construction and development of sub-cities, meeting the leisure needs of sub-cities residents, improving the quality of life, and alleviating problems related to traffic congestion and big city diseases in the city on weekends and holidays.

## 4.2 Conclusions

Based on the survey of residents' leisure activities and their actual leisure travel flows, this paper comprehensively analyzed the characteristics of Shenyang residents' leisure activities and the corresponding leisure space structure. The following conclusions were drawn from the results of the analysis.

First, through a questionnaire on the leisure activities of Shenyang residents to analyze the residents' leisure activity preference, home leisure was found to be the first choice for residents' leisure activities. Leisure time affects leisure activities. On weekends and holidays, Shenyang residents were more willing to engage in outdoor leisure activities. The proportions of residents shopping in malls and walking in parks were relatively close. Leisure spaces with low travel costs and high accessibility were more attractive to residents.

Second, the measured flows of residential-shopping and residential-park were identified using mobile phone signaling data, which can characterize the actual leisure activities of Shenyang residents. The average travel distance for resident leisure activities displayed the spatial characteristics of near in the middle and far in the periphery. The central part of the city was well-equipped with leisure facilities, and most residents in this area were close to leisure activities. Residents living in the periphery of the city chose to travel greater distances to

the central part of the city for leisure activities on weekends and holidays, during which there were problems such as traffic congestion and parking difficulties often occurred in the central part of the city.

Third, the flow of residential-shopping and residential-park functional relationships in Shenyang displayed a clustering mode, and the development trend of the urban monocenter was remarkable. The residential-shopping network was divided into three communities, namely northern, southern, and western communities divided by Taiyuan Street, Xita Street, and Jihong Street in Tiexi District. The shopping facilities in the central area were more attractive to residents, and the shopping activities had the characteristics of centripetal agglomeration. Residents' shopping leisure activities were mainly concentrated in the southern community, and the northern and southern communities were relatively closely connected. On weekends and holidays, traffic congestion tended to occur in the north-south direction of the city. The western community was relatively unattractive to residents in other communities across the regions, and the flow of shopping leisure activities in the east-west direction was less.

Fourth, the residential-park network was divided into four communities with strong spatial regularity in the east, south, west, and north; overall, park functions generally served the nearby residents. Park facilities in the western community were the most attractive to residents in other communities. The interactive, two-way connection between the northern and western communities was the closest. Residents in the southern community traveled more and had the shortest average distance to the western community for park leisure activities. Due to the lack of attractive park facilities in the eastern community, the number of eastern community residents traveling to other communities for park leisure was the highest among the residents in all communities.

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