Research on Application of Gradient Analysis to City Green Space Accessibility——Taking garden green space of Taian central city for instance

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Abstract. Green space accessibility can be used to measure the potential of green space to provide services to residents. In this study, based on the spatial analysis function of GIS software and combining with the distribution of road network of Taian central city, gradient analysis was firstly introduced to analyse accessibility and its spatial distribution character of garden green space quantitatively. Results showed that whole accessibility of garden green space of Taian central city is good whichever transportation was adopted. Most of the regions could arrive at the nearest garden green space within 5 minutes. Accessibility of the centre area was better than that of the edge, and accessibility of the north area was better than that of the south. To some extent, there is relative between gradient distribution of accessibility and that of area of garden green space.

1. Introduction

Accessibility refers to the relative or absolute difficulty of overcoming resistance from any point in a region to another point. It reflects the spatial resistance overcome from one point to another, which can be expressed by distance, time, cost, and other indicators [1-2]. Accessibility, which was first used in traffic planning, is an effective index to measure traffic network structure [3]. At present, it has been widely used in regional planning [4], tourism planning [5-6], urban public facilities planning, [7-8] and other fields. The accessibility of green space intuitively indicates the amount of service opportunities which green space provides to residents, and to a large extent represents the fairness and rationality of urban residents’ uses of green space as a kind of urban public resources [9-10].

The gradient analysis method is also known as the moving window method, which is commonly used in the landscape pattern analysis, such as the land use pattern [11-12], the urban space pattern [13-15], and the green space pattern[16-17]. It is also used to represent spatial distribution characteristics of the research objects in the direction and the distance. This method was also used in some studies to analyze the architectural landscape pattern [18]. However, application of this method in the study of urban green space accessibility has not been reported.

Based on the spatial analysis function of software Arcgis10.2 and combined with the distribution of road network, the green space accessibility of Tai’an central city was analyzed in this study by using the travel cost method. The gradient analysis method was introduced firstly to quantitatively analyze...
spatial distribution characteristics of green space accessibility to provide guidance for the rational layout of city green space system.

2. Research methods

2.1 General situation of the study area
Tai’an city which area is 6598km$^2$ is located in the middle of Shandong Province and the world culture and natural heritage Mount Tai is located in it. Tai’an city is surrounded by mountains and rivers which ecological environment is excellent. It is one of the first batch of tourist cities to open to the outside world and one of the National Famous Historical and Cultural City of China. By the end of 2016, the city’s green coverage rate is 44.7% and the per capita garden green space area is 19.9m$^2$.

The scope of this study is the central district of Tai’an City, north to Mount Tai, west to the Great Wall Road, south to the Panhe Street, east to Shanggao Street Office, including Caiyuan Street Office, Daimiao Street Office and Taiqian Street Office. The total area is 36.4km$^2$.

2.2 Data sources
The data used were from the 1:10000 map of land use type of Tai’an city in 2016. Green space data was provided by Tai’an Municipal Bureau of Parks and the community population data was from the sixth national census of 2010.

2.3 Evaluating indicator
The evaluation index of the accessibility of the park green space from any point in the research area was:

$$A_i = \min(M_i T_{ij})$$  \hspace{1cm} (1)

i refers to any point in the research area. $T_{ij}$ refers to the time of point i arriving at Park j through the shortest route of the traffic network. $M_i$ refers to the weight of park i. Regardless of landscape attraction and other factors, traffic accessibility is considered only and the weight is 1. $A_i$ refers to accessibility of point i within the area [19].

2.4 Procedure of accessibility calculation

2.4.1 Preparation of source files.
Based on the ARC/INFO software, the garden green space information was extracted from the land use map (Figure 1).

2.4.2 Preparation of travel cost documents (road network documents).
Based on the ARC/INFO software, the road network information was extracted from the land use map (Figure 2).

Tai’an central city is divided into several grids and every grid has the dimension of 30m×30m. Compared to 36.4km$^2$ of the central city area, each grid area is small enough to be considered as internal homogeneous unit and the accessibility is the same.

Time is the standard for measuring accessibility, so space distance is transformed into time distance through the speed. That is the time needed for the city residents to pass a grid (30m). There are three trip modes in the study: walking, non-motor vehicles, and motor vehicles. The road network was divided into three levels: main roads, secondary roads, and branches. Different speed and travel costs were set to different levels of roads. The values of travel costs for different transportations were shown in Table 1.
Table 1. Values of travel costs

|                  | Walking | Non-motor vehicle | Motor vehicle |
|------------------|---------|-------------------|---------------|
| Average speed (km/h) | 5       | 15                | 60            |
| Values of travel cost (s/grid) | 21.6    | 7.2               | 1.8           |
|                  |         | 45                | 2.4           |
|                  |         | 30                | 3.6           |

2.4.3 Calculation of accessibility of garden green space.
The time from each grid to the nearest garden green space was calculated and the accessibility of garden green space in the study area was obtained.

2.5 Gradient analysis of accessibility
In order to express the spatial distribution of the accessibility, the gradient analysis method was adopted to analyze the gradient distribution characteristics of the accessibility of the green space in the four directions from different distance to the center of the city.

Taking the center of the study area (the railway station) as the center point, two transect belts of 500m x 1000m were set up from west to east and north to south to form a "cross" axis and several sample plots, which extended to the boundary of the study area (Figure 3). It was defined that the north and the west regions of the center point were negative and the east and the south regions of the center point were positive. With the support of ARC/INFO software, the "cross" axis diagram and accessibility distribution figure were operated with raster calculation, the average accessibility of each sample was calculated, and the value was assigned to the central grid of each sample.

3. Results and analysis

3.1 Accessibility analysis
The minimum value of the time taken by each of the three modes of transportation to any point in the study area through the traffic network, that is, the accessibility of the point to the garden green space, was calculated, respectively. As shown in Figure 4 and Table 2, the grade distribution of accessibility of garden green space under three traffic modes was obtained at an interval of 5 minutes, and the cumulative distribution frequency of accessibility in each time period was obtained.
Figure 4 and Table 2 indicated that:

1. No matter which kind of transportation is adopted, most parts of the study area could reach the nearest garden green space within 5 minutes and the overall accessibility was well. The accessible areas reached 62.0%, 83.6%, and 93.6% within 5, 10 and 15 minutes by walking, respectively. The accessible areas reached 71.4% and 85.1% by taking non-motor vehicles and motor vehicles, respectively.

2. Accessibility of some areas was undesirable (more than 10 minutes) under the three modes of transportation. These communities, of which population accounted for 3.6%, are Jinxing Community, Lingzhi Community of Caiyuan Street Office, and Yinchun Community and Nanhu Community of Daimiao Street Office. The walking time was more than 15 minutes, and time needed by taking non-motor vehicles and motor vehicles was also more than 10 minutes.

3.2 Gradient analysis of accessibility

The gradient analysis results of accessibility of different traffic modes were shown in Figure 5.
The gradient analysis results of accessibility of walking showed that the accessibility time of walking mode in all four directions was less than 15 minutes, and that in most areas was less than 10 minutes. The accessibility of some areas in the east-west direction was poor, and the accessibility in the north-south direction was better than that in the south.

The gradient analysis results of accessibility of non-motor vehicle transportation mode show that the accessibility time of most areas of the four directions was within 6 minutes. The accessibility time of most area in the east-west direction was less than 5 minutes and accessibility of the north area was better than that of the south area in the north to south direction. Overall, accessibility of the central area (about 3 minutes) was superior to that of the edge zone.

The gradient analysis results of accessibility of motor vehicle traffic mode showed that the accessibility time of most of the regions in the four directions were within 4 minutes. The accessibility time in the east-west direction and in the north-south direction were between 1 and 6 minutes and the accessibility of the central zone was better than that of the edge zone.

In a word, no matter what kind of transportation mode was adopted, it could be summarized that:

1. The accessibility of the central area of the city was better than that of the marginal zone, which was related to the concentrated distribution of garden green space and the high density of the road network in the central area of the city.

2. The accessibility of the north area of the city center was better than that of the south area. The reason was that several large comprehensive parks such as Daizongfang Park, Longtan Park, Hushan Park, and Municipal Square were distributed in the north of the city center, while only a few large parks such as Donghu Park and Nanhu Park were distributed in the south of the city center.

3.3 Correlation between gradient distribution of accessibility and gradient distribution of garden green space area

To reveal the relationship between accessibility distribution and garden green space distribution further, correlation analysis (Table 3) was studied between gradient distribution of accessibility and the area gradient distribution of the garden green space with three traffic modes (Figure 6).

It could be seen from Table 3 that the gradient distribution of accessibility of the three transport modes was negatively correlated with the area gradient distribution of the garden green space to a
certain extent. That was, the larger the area of the garden green space was, the better the accessibility would be. The correlation coefficients in the north-south direction were smaller than that in the east-west direction. That was, accessibility and the area of the garden green space showed a greater negative correlation in the north-south direction than in the east-west direction.

Table3. Correlation Analysis between accessibility and Park Green Space area

|                | Walking (min) | Non-motor vehicle (min) | Motor vehicle (min) |
|----------------|---------------|-------------------------|---------------------|
| East-West      | -0.22         | -0.25                   | -0.23               |
| South-North    | -0.65         | -0.61                   | -0.61               |

On the whole, the gradient distribution of accessibility was related to the area gradient distribution of garden green space to a certain extent, but it was not very obvious, the maximum value was -0.22 and the minimum value was -0.65. The reason could be that accessibility was the result of the comprehensive factors, including the area, quantity, attraction of garden green space, and road network distribution of the city. The method used in this study did not consider the attractiveness of garden green space landscape quality to citizens, which was also an important accessibility research direction in the future.

4. Conclusions and suggestions

Basing on GIS spatial analysis and combining with gradient analysis, the spatial distribution characteristics of garden green space accessibility in Tai’an central city were obtained. The conclusions of this study were as follows:

(1) No matter what kind of traffic mode was adopted, the time to reach the nearest garden green space in most of the study area was less than 5 minutes, and the accessibility was good. Accessibility of some areas was poor (more than 10 minutes). These areas mainly included Jingxing Community, Lingzhi Community in Faiyuan Street, Yingchun Community, Nanhu Community in Daimiao Street, and etc.

(2) Accessibility of the city center was better than that of the marginal zone. Accessibility of the north of the city center was better than that of the south of the city center.

(3) Accessibility gradient distribution was correlated with the area gradient distribution of garden green space to a certain extent.

The influence factors of the accessibility of garden green space were various, such as the quality of the landscape, the service level, the economic development level of the city and, etc. These factors have not been further studied yet. The calculation of the accessibility of this study was a barrier-free accessibility and did not take into account the factors such as the setting of the traffic light at the intersection. The gradient analysis was only a reflection of the accessibility distribution characteristics in the four directions, but the calculation method was a useful attempt of the accessibility analysis. If data of more years could be obtained to comprehensive represent the accessibility of the temporal and spatial distribution characteristics, the method could be used for more comprehensive analysis and evaluation of the urban green system which would lead to greater guidance for the scientific layout of the urban green space system.

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