Analysis on the spatial accessibility of parks and green spaces and optimal site selection—Taking Weifang prefecture-level city as an example

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Abstract. Based on the ArcGIS platform, we took the parks and green spaces of the improved potential model to analyze the spatial accessibility of local parks and green spaces in Weifang prefecture-level city via combining traffic and population distribution with the distribution of parks, and cuckoo search algorithm to optimize the site selection of park green space. According to the results of the accessibility analysis. The results show that: (1) the distribution of population and green spaces is not balanced. Parks are mainly distributed in the downtown, while they are fewer in the township. (2) The spatial accessibility of the park green space is significantly different between areas, and the southeastern and northwestern areas are higher than other parts. (3) We optimize the location of green spaces to achieve fairness in areas with low accessibility of parks and green spaces. The article intuitively reveals the different accessibility of parks and green spaces in various streets of Weifang prefecture-level city, effectively distinguishes their scarcity, and provides a scientific basis for the space allocation and optimization of park green spaces.

1. Introduction

Parks and green spaces are referred to as service facilities with certain rest functions, open to the public, mainly for playing and relaxation, and vast ample green land with functions such as viewing and avoiding danger at the same time [1]. The rapid development of cities has brought about traffic congestion, environmental pollution, and other problems, and at the same time has accelerated the pace of people's lives. The number, size, and spatial layout of parks and green spaces directly affect the quality of the urban environment and the living standards of residents [2]. Parks and green spaces can meet the life demands of urban residents for parks and green spaces for entertainment and various outdoor sports [3]. Therefore, the accessibility of parks and green spaces has always been the current focus and research object. Moreover, the increase in the number of parks and green spaces is a necessary means to satisfy the everyday contemporary lives of residents.

Spatial accessibility refers to how easy it is for residents to overcome a specific resistance to reach another service facility, and it is an important criterion to measure the reasonable spatial layout of urban service facilities [4]. With the development of 3S technology, scholars began to apply GIS spatial analysis to the accessibility of urban parks and green spaces. Nicholls [5] used spatial analysis
methods to evaluate the accessibility and fairness of park green spaces. Xiong Huijin [6] used the technique of network analysis to analyze the accessibility of parks and green spaces in Nanchang. X. Zhou [7] discussed the accessibility of parks for different ethnic groups in six cities in Illinois, combining the distribution of parks and tree canopies. Shi Tuo [8] used the method of combining network analysis and buffer zone to analyze the accessibility of urban parks in Shenyang. Refining urban park system planning and green space system planning through the evaluation of park accessibility will focus on the research and application of accessibility theory. The potential model takes into account the effect of distance attenuation, and accurately measures the difficulty of the residents to the park green space.

Yang [9] proposed a multi-objective cuckoo search algorithm, which applying to multi-objective problem optimization. Hui Qian [10] measured the Xi'an Big Wild Goose Pagoda based on walkability and used a particle swarm algorithm to obtain the optimal solution for the newly added park. Zhou Yuan [11] used GIS and a multi-target area location configuration model to select the location of Shenyang parks. In the current study, genetic algorithm, ant colony algorithm, particle swarm algorithm are widely used, still these algorithms have the characteristics of slow convergence, easy to fall into local optimal, search is easy to stagnate or premature, etc., it is necessary to find a way to solve the optimization location problem. The Cuckoo search algorithm has the advantages of few parameters, simple operation, high search efficiency, random search path optimization, strong optimization ability. It is widely used in various fields and has become a new heuristic algorithm after GA and PSO [12-13]. The Cuckoo search algorithm builds a location model to make the park layout achieve spatial fairness, improves efficiency, and reduces the right justice of residents using public services differences.

Since most of the current researches focus on first-tier and second-tier cities, and lack of research on ordinary third-tier cities. There are many rural areas in Weifang, the analysis of the accessibility of parks and green spaces in this area and the optimization of site selection can better respond to the country’s rural revitalization, and policies to build a civilized village. This study takes Weifang’s parks and green spaces as the research object. With the help of an improved potential model, the accessibility analysis is carried out from the spatial layout of the parks and green spaces in the city, which enriches the evaluation methods of parks and green spaces. It conducts the park green spaces according to the results of the accessibility analysis. The spatial layout and site selection of Weifang prefecture-level city provides guidance and a scientific basis for the reasonable layout and construction of green space in Weifang prefecture-level city’s parks.

2. Overview of the study area and data sources
Weifang prefecture-level city, Shandong Province, is located in the middle of the Shandong Peninsula. It has jurisdiction over four districts, six county-level cities, and two counties, with 58 sub-districts and 62 townships. Figure 1 shows the location map of county-level administrative divisions. According to POI, there here are parks and green spaces in Weifang prefecture-level city, and the distribution of parks is shown in Figure 2.
Figure 1. Study area. 
Figure 2. Distribution of park green space.

The population data is obtained from the 2016 Weifang Statistical Yearbook and the statistical yearbooks of counties and districts in Weifang. The data of parks have come from the profile of each park’s official website and telephone consultation. The road network data is obtained from OSM (Open Street Map: www.openstreetmap.org) and the official website of the Shandong Provincial Geographic Information Public Service Platform. Due to the complexity of the road network, it is necessary to preprocess the road network and using ArcGIS to check the topology of the road network to optimize the existing road area to ensure the connectivity of the road network, using ArcGIS to digitize relevant information to establish a database for accessibility analysis.

3. Research methods

3.1. Improved potential model

The potential model only considered the demand of the supply side and ignored the competition between the demand side. Joseph [14] added the population size influencing factor to the general formula of the potential model, as shown in equation (1).

\[
A_i = \sum_{j=1}^{n} \frac{M_j}{D_{ij}} V_j = \sum_{k=1}^{m} \frac{P_k}{\beta_{kj}}
\]

In the formula, \(V_j\) represents the impact factor of the population scale; \(P_k\) represents the population of the township street; \(M_j\) represents the activity scale at points \(j\), expressed by the area of park green space; \(D_{ij}\) represents the travel impedance factor at point \(i\) and point \(j\), expressed by distance; \(n, m\) represents the number of parks and green spaces and township. \(\beta\) represents the friction coefficient. Research [15-17] believed that the value of \(\beta\) mainly refers to the range of [0.9-2.9]. After comparison, the value of \(\beta\) is 1 for the accessibility of park green space, so \(\beta=1\) in the text.

3.2. Cuckoo search algorithm

Site selection for parks and green spaces is a process that is affected by multiple factors. There are more restrictive conditions in the site selection process, and it is impossible to consider every aspect of the planning process. This paper takes spatial fairness as the standard and distance as the main factor to construct the objective function. The unit distance cost of residential areas and parks and green spaces is only related to reach and has nothing to do with the geographical location of parks; that, is the length of reach, the higher the cost. The cuckoo search algorithm is basing on the cuckoo’s nest-finding parasitic habit. The basic assumptions of the algorithm are as follows:

1. Each cuckoo lays only one egg at a time and is randomly stacked in a bird’s nest to hatch;
(2) The eggs in the nest of the highest quality are retained to the next generation;
(3) The number of nests in which cuckoos can place eggs is a fixed value \( n \), and the probability of eggs being found is \( P_a \) (0<\( P_a <1 \)).

According to the above three assumption rules, the cuckoo search algorithm updates the search location and path as formula (2)

\[
x^{(t+1)} = x_i^t + \alpha \Theta L(\beta)
\]

In the formula, \( x_i \) is the individual \( i \) in the nest of the \( t \) generation; \( \Theta \) is the quantity product; \( \alpha \) is the step control amount, usually identified as 1; \( L(\beta) \) is the random search path. The construction model is showing in formula (3)

\[
T = \sum_{i=1}^{NG} \sum_{j=1}^{NH} d_{ij} N P_j
\]

In the formula, \( d_{ij} \) is the distance between the residential area and the green space in the park; \( NP_j \) is the number of residents using the green space in the garden; \( NG \) is the number of townships, and \( NH \) is the number of the park.

4. Spatial analysis and optimal site selection

4.1. Analysis of the spatial accessibility of Park Green Space

The spatial accessibility of the existing parks in the Weifang prefecture-level city is imbalanced, with significant differences in area and the uneven distribution. Parks are mainly distributed in the urban area, while less spread in the township. It can be seen from Figure 2 that parks and green spaces are concentrated in the city center, while towns and some small parks are only distributing in the township. As shown in Figure 3, there are more parks and green spaces in areas with higher population density. It can be seen from Figure 4 that the center, northwestern, and southeastern parts of the city have better accessibility, while the east and west parts are relatively poor. Regions with higher accessibility are distributing in areas with lower population density. It can be seen from that there is a specific particular misplaced phenomenon between the accessibility distribution of parks and the distribution of population density, especially in the north and southwestern of the city. The higher accessibility of park green space does not match the lower population density distribution. The distribution of green space in the park is unreasonable, increasing residents’ difficulty gaining the green space resources.

4.2. Optimal site selection for parks and green spaces

Aiming at the existing park and green space in line with the actual overall distribution, this paper used the cuckoo search algorithm to optimize the location of the parks and green spaces in Weifang prefecture-level city, so that residents can enjoy the services of the parks and green spaces in a timely and effective manner. Based on the original park green space, a certain amount of park green space \( n \) is added. Under normal circumstances, the number of new additions \( n \) is usually set to 15-40.
Therefore, this paper uses different parameters to conduct experiments and compare the results of optimized parameters. In this paper, we will analyze the results with \( n = 15, n = 30, \) and \( n = 40 \), and the number of iterations is 5000 [18-19]. The shortest average distance between each residential area and the newly-added park green space is calculated as shown in Table 1. The result shows that when \( n = 40 \), the average travel distance of residents is the shortest, when \( n = 15 \), the average travel distance of residents is the longest, it is between 15 and 40 when \( n = 30 \), so when \( n = 40 \) The location of the park and green space is optimal at that time. After adding these parks, making the distribution of the park green space in Weifang more balance. As shown in Figure 5, after the site selection analysis by the cuckoo algorithm, the park green space of Weifang prefecture-level city effectively reduces the difference in the ability of residents to obtain park green space services. The calculation results are better, most of which are distributed in regions with low accessibility, indicating that the cuckoo search algorithm can solve green space in parks.

Table 1. The average travel distance of residents.

| \( n \) | average travel distance of residents/m |
|-------|--------------------------------------|
| 15    | 23113.94688                          |
| 30    | 12311.01312                          |
| 40    | 10969.13325                          |

4.3. Discussion

Based on the improved potential model, this paper comprehensively evaluates the accessibility of Weifang's parks and greens, finds problems and proposes a reasonable optimization strategy for greening, and improves the accessibility of Weifang's parks and green spaces to achieve the result of nearby recreation for current residents. From the results of accessibility, the distribution of green space in parks is uneven, and the overall distribution of parks varies significantly in number and area. Most of the regions with higher population density are less distributed. Studies have shown that the optimization of the layout of parks and green spaces is mainly based on the balance of supply and demand and the perspective of residents' travel [20-21], such as the addition of buses and subways, multiple layouts of community parks, community parks, etc. In this paper, the park green space optimization strategy is mainly based on park accessibility, quantitatively analyzes the park green
space accessibility, and provides a scientific basis for the rational planning of park green space. Regarding the addition of green space, only the current new location can be determined, and the size of the new addition cannot be determined, the dynamic study of park green space in time series is not considering. Therefore, accessibility should be considered comprehensively in future research.

5. Conclusion
This paper adopts an improved potential model, starting from the supply-demand relationship between population and park green space, the number, area, spatial distribution of park green space, and the number of residents, density, and spatial distribution of the park green space are studied for accessibility. The cuckoo search algorithm uses to analyze the local optimizing the location of the park green space, providing a reference for the planning of the park green space in Weifang prefecture-level city. (1) the distribution of population and green spaces is not balanced, with large differences in area and uneven population distribution. Parks are mainly distributed in the urban area, while less distributed in townships. (2) There is a significant difference in the spatial accessibility of parks and green spaces. The accessibility of the southeastern and northwestern of the city is higher than other parts. The accessibility of the city center is moderate, and the accessibility of other areas is low. (3) To optimize the site selection of parks and green spaces, it is necessary to coordinate the space allocation and development of parks and green spaces, appropriately expand the area of central parks and green spaces, promote the upgrade of the central parks and green spaces, followed by increasing the distribution of parks and green spaces in the township to improve the life of rural people. The cuckoo search algorithm can effectively optimize the location of urban parks, provides scientific guidance for the spatial layout of urban parks and green spaces, enabling the park green space to form an organic overall in the city space.

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