Study on Site Selection and Layout Planning of Public Toilets in Urban Comprehensive Park: Taking Xuanwu Lake Park in Nanjing as an example

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Abstract. Reasonable location and layout of public toilets can ensure the use efficiency of toilets in the park, and improve the use experience of tourists and satisfaction with the park. (1) Based on the background of "tourism toilet revolution", this paper summarizes the existing methods to solve the problem of facility location, and analyzes the possibility of facility location in urban park. (2) This paper summarizes the single constraint conditions of the existing facilities location, less considering the flow of people and other issues, proposes and establishes a multi-level, multi constraint condition location model. (3) The optimization model proposed in this paper is applied to the location and layout of public toilets in Xuanwu Lake Park, Nanjing. (4) The location model proposed in this paper can meet a variety of constraints at the same time, and provide a more convenient, scientific and economic location method for urban park public toilets and other infrastructure services, landscape buildings, and provide reference for other types of urban park landscape building facilities location.

1. Introduction

Urban comprehensive park is a special existence in urban public recreational space and an important part of park green space. Its service scope is wider, its function is more comprehensive, and its area is larger (more than 10 hm2). It is the main place for urban residents' weekend leisure activities [1,2]. Therefore, tourists need more public toilets and services than other types of park green space. At present, public toilets in urban comprehensive parks have become one of the important factors affecting tourists' satisfaction. To a certain extent, public toilets reflect the service level of urban comprehensive parks and are the key to embody the quality of a park's tourism. Scientific and reasonable planning and layout of public toilets in urban parks can improve tourists' travel experience as well as the comprehensive evaluation level of the park. Public toilets are the product of the city's continuous development. As early as the 4th century before the park, the rudiment of urban public toilets appeared. As early as 2005, some foreign scholars put forward suggestions on how to optimize the location of public toilets according to the existing problems of public toilets in urban parks [3].

Facility location has been a central issue in operational research since the early 1960s. The quality of location directly affects the service quality, efficiency and cost of the selected facilities. Facility location problem includes three basic problems: P-median problem, P-center problem and coverage problem [4-6]. This paper mainly refers to the application of coverage problem in facility location problem, so as to carry out the research in this paper.
At present, at the level of urban research, the research on facility location decision-making [7] is mostly focused on urban public services [8-10] and risk aversion [11-14]. This kind of research methods mainly focus on the natural environmental factors and accessibility related to the location of the selected facilities. For the location decision-making of transportation, medical treatment, fire garbage disposal and other facilities, the hierarchical analysis method combined with ArcGIS is used to solve the location problem step by step [15, 16]. However, for some special facilities, the constraints of the location method are single, and the number of people serving facilities and the cost of construction are not considered. At present, in the research on the location of urban public toilets, the main factors affecting the location include:

(1) Accessibility: Mainly used to ensure the rationality of the layout of public toilets in density, can be used as an index to check whether the layout of public toilets is reasonable [17-20]. In addition, the layout of public toilets should take into account the scope of service of road public toilets, so as to ensure that visitors can reach the public toilets in a suitable time when they need it [21-23].

(2) Landscape coordination: It can ensure that the landscape layout of urban parks is more coordinated, create a good park tourism atmosphere, and improve the visual experience of tourists [23, 24].

(3) Service efficiency: Public toilets should be located in the main scenic spots, Park entrances and exits and other tourist centers. Public toilets in this location can greatly improve the use efficiency of public toilets, and the service efficiency of public toilets will also be improved [25-27].

(4) Pollution: The layout of public toilets should pay attention to its pollution, and should be close to the urban sewage network and away from the water purification network [17]. According to "Code for the design of public park (GB 51192-2016)", public toilet sewage is discharged into urban sewage pipeline instead of into the internal water system of the park.

In the research on the location of public toilets, ArcGIS technology has been gradually used in urban planning for the location and layout of public toilets. However, in the planning and design of landscape architecture, the location and layout of public toilets is still in the theoretical research based on design norms. The layout is mostly based on design experience and aesthetics. To a certain extent, subjectivity lack of scientific and rational planning and layout research. According to the single restriction of facility location and the current planning of public toilet location in urban parks, this paper puts forward an innovative location strategy: a location model based on multi-level and multi-constraints.

2. Research methods

2.1. Survey and data description of the study area

Xuanwu Lake Park, located in Xuanwu District of Nanjing City (Figure.1), is an important part of Zhongshan Scenic Area, a national scenic spot. Xuanwu Lake Park lies on Zijin Mountain in the East and on the wall of Ming City in the west. It is the largest Royal Garden Lake in China. Xuanwu Lake Park covers a total area of 502 hectares, of which water surface is about 378 hectares, Lake circumference is 15 Km, and land area is about 128 hectares [28].

Figure 1. Location of Xuanwu Lake Park.
Data mainly includes three parts: literature, standardized data collection, field research data and spatial information data. (1) Requirements for the scope, accessibility and quantity of public toilets in urban parks obtained through literature review. (2) Through questionnaires, interviews and on-the-spot exploration, the demand of park visitors for public toilet service capacity is obtained. (3) The Park CAD topographic map is used to construct spatial information in ArcGIS and determine the location of public toilets.

2.2. Technology roadmap
As the constraints of public infrastructure location are relatively single, this paper proposes a multi-constraints and multi-level location model, which is mainly divided into three parts (figure 2):

![Figure 2. Technical Route.](image)

Part I: Basic data acquisition and data processing. It mainly includes terrain data processing, site spatial data processing, current land use type analysis and suitability evaluation, WeChat (China's popular instant messaging software) suitable for pedestrian flow data processing and human flow thermodynamic map drawing.

Part II: Evaluation of current facilities: the first step is to evaluate whether the total number of service personnel of existing facilities in the park can meet the needs of park users, and whether the accessibility can meet the demand of tourists to the nearest public toilet within 500m [28]. If the current situation is satisfied, the optimization and upgrading scheme design will be carried out; otherwise, further optimization will be carried out to meet the primary site selection requirements. The second step is to grade the service quality of public toilets, determine whether there are facilities that can be optimized and upgraded, and evaluate the area, flow of people and accessibility of facilities.

Part III: Site selection scheme of facilities under mathematical model constraints. Constraint condition model is established and site selection calculation is carried out at two levels: (1) Primary facility point selection is mainly used to meet basic physiological needs of public toilets. This paper does not set the current situation of public toilet demolition considering economic conditions. Secondly, the maximum coverage model is used for primary site selection planning. (2) The mathematical constraint model is used to express the constraint conditions, and the algorithm is used to calculate.

2.3. Model building
According to the existing characteristics of public toilets in parks and the premise of multi-standard service radius, this paper uses the coverage problem-maximum coverage problem as the theoretical basis to explore the location of public toilets in parks. Considering the practical significance of construction, this paper sets constraints to optimize the preliminary location scheme from the perspective of economy, so that the optimized location point can meet more people and more people. Multiple public needs, including:
(1) Flow coverage constraints: in order to ensure that the effective number of public toilets can serve basically meet the number of visitors in the park, priority should be given to optimizing the areas where the distribution of human flow is more intensive.

(2) Accessibility constraints: to meet the needs of accessing the nearest public toilet from various scenic spots, entrances and exits of the park, and the distance between adjacent public toilets should not exceed 500m.

(3) Restriction of service scope: The service scope of public toilets should basically cover the land areas accessible to park visitors. At the same time, the constraints to a certain extent limit the number of public toilets, avoid too many or too few, so as to make it in a suitable value.

According to the basic information obtained and the basic situation of public toilet layout obtained by field investigation, a mathematical model is established. The specific model is as follows:

\[ w \] Total number of public toilets available.
\[ i \] Location of public toilets.
\[ N \] The number of facilities selected as independent fixed public toilets.
\[ \text{Suit}_i \] When the location \( i \) is in a suitable position for the construction of public toilets, \( \text{Suit}_i = 1 \), otherwise \( \text{Suit}_i = 0 \).
\[ \text{Qua}_i \] Effective coverage of toilet location points.
\[ \text{IdealSum} \] Ideal total number of people served.
\[ x_i \] 0, 1 binary variable, When location \( i \) is the public toilet location facility point, \( x_i = 1 \), otherwise 0.
\[ y_i \] 0, 1 binary variable, \( y_i = 1 \) when the location point \( i \) is within the total service range of the alternative public toilet location point \( j \), otherwise 0.
\[ D_{ij} \] Distance between facility points \( ij \).

2.3.1. Evaluation of Present Layout Scheme of Public Toilets.

Based on the above argument, when the number of public toilets does not meet the demand, it needs to increase the number of public toilets. In addition, according to the mathematical model given above, it verifies whether the layout of public toilets in urban parks can meet the needs of tourists. If it can be, it does not need to be adjusted. If not, the layout of public toilets is designed and optimized.

\[ \sum_{i=1}^{w} x_i \geq 1 \quad (1) \]

\[ \sum_{i=1}^{w} y_i = w \quad y_i = 0 \quad D_{ij} > 500 \]

\[ y_i = 1 \quad D_{ij} \leq 500 \quad (2) \]

\[ \sum_{i=1}^{w} x_i \times \text{Qua}_i \geq \text{IdealSum} \quad (3) \]

Among them, (1) it means that the number of public toilets in the comprehensive park should meet the basic condition that the number of public toilets is greater than 1; (2) ensure that every public toilet point is within 500 meters walking distance of public toilets; (3) it means that the number of effective public toilets in the park should be greater than the ideal number of public toilets. When the above conditions are met at the same time, it can be considered that the number of public toilets in the park meets the basic needs of the park, otherwise, it means that the improvement scheme is needed.

2.3.2. Preliminary Site Selection Scheme: Facility Point \( N \) to Meet Scale Demands.

The meaning of objective equation (4) is to select the least number of public toilets \( n \), in order to save construction costs. Equations (5) - (8) are constraint functions, in which constraint formula (5) guarantees that each public toilet location point is within the 5-molecular-walk (400m) range of independent fixed public toilets; constraint formula (6) ensures that the number of independent fixed public toilets (i.e., the number of sites \( n \)) is at least 1; constraint formula (7) limits the land use property
of the site if it does not meet the needs of public toilets construction. If so, it is prohibited to build an independent fixed public toilet. Constraint formula (8) ensures that the number of public toilets serving can meet the needs of tourists who need public toilets in the park.

\[
\text{Goal } \quad N = \min \sum_{i=0}^{w} x_i \tag{4}
\]

Subject to

\[
\sum_{i=1}^{w} y_i = w \quad y_i = 0 \quad D_{ij} > 500 \tag{5}
\]

\[
y_i = 1 \quad D_{ij} \leq 500
\]

\[i\] is the closest location point to facility point \[j\]

\[
\sum_{i=1}^{w} x_i \geq 1 \tag{6}
\]

When \(x_i = 1\), \[\sum_{i=1}^{w} Sui_i > 0 \tag{7}\]

\[
\sum_{i=1}^{w} x_i \times Sui_i \times Qua_i \geq \text{IdealSum} \tag{8}
\]

2.3.3. Optimal economic solution of construction with N-value limit.

The facilities selected by ArcGIS location allocation can only meet one condition, such as the maximum coverage area, the minimum facility point, etc. This paper considers the location of public toilets meeting multiple conditions: on the premise of finding out the location scheme \(n\) of public toilets with the largest service coverage range through location allocation, we can find out the minimum number of public toilets that can cover the park’s tourist flow. Under this scheme, the economic construction cost is the lowest. In addition, under the limit of the number of sites with the lowest construction cost (i.e. \(N\) value), there are a variety of site selection schemes, and the optimal site selection and construction scheme are selected to make the public toilets serve the largest number of people and meet the demand of the highest service efficiency of public toilets. The purpose of this program is to find the solution of the maximum number of service personnel under the limit of the optimal number \(n\) on the basis of the optimal number \(n\) obtained above.

\[
\text{Goal } \quad N = \max \sum_{i=0}^{w} x_i \times Qua_i \tag{9}
\]

Subject to

\[
\sum_{i=1}^{w} y_i = w \quad y_i = 0 \quad D_{ij} > 500 \tag{10}
\]

\[i\] is the closest location point to facility point \[j\]

\[
\sum_{i=1}^{w} x_i \geq 1 \tag{11}
\]

When \(x_i = 1\), \[\sum_{i=1}^{w} Sui_i > 0 \tag{12}\]

\[
\sum_{i=1}^{w} x_i \times Sui_i \times Qua_i \geq \text{IdealSum} \tag{13}
\]

Among them, the meaning of objective equation (9) is to select the largest number of people to serve in order to improve the service efficiency of public toilets. Equations (10) - (13) are constraint functions,
in which constraint formula (10) guarantees that each public toilet location point is within the range of 5-molecule walking 500m of independent fixed public toilet; constraint formula (11) ensures that the number of independent fixed public toilets (i.e., the number of sites n) is at least 1; constraint formula (12) restricts the land use property of the site if it does not meet the requirements of public toilet construction If necessary, it is prohibited to build independent fixed public toilets. Constraint formula (13) ensures that the number of public toilets serving can meet the basic needs of tourists who need public toilets in the park.

On the basis of the mathematical model, the model is solved by computer programming. According to different model parameters, the main parameters in the input data are the accessibility of alternative public toilets, the capacity of public toilets, and whether the location is suitable for the construction of parks.

3. Case verification

3.1. Data Processing and Current Situation Evaluation in the Research Area

According to the total area of Xuanwu Lake and the Standards for Setting up Environmental Sanitation Facilities GB/T50337-2018, 25-30 public toilets should be installed in Xuanwu Lake Park. At present, there are 20 public toilets in Xuanwu Lake Park (Figure.3), including independent public toilets, temporary mobile public toilets and building accessory public toilets. The insufficient number of public toilets leads to the inadequate coverage of public toilets' service area and human flow coverage, which can’t meet the needs of primary site selection. Xuanwu Lake Park is gradually increasing the number of public toilets, according to the Xuanwu Lake Management Office announcement, but how to reasonably determine the location of public toilets to achieve the construction of a small number of public toilets to meet the needs of tourists is an urgent problem to be solved.

Figure 3. Current Situation of Public Toilet Distribution

3.2. Primary Facility Location Scheme to Meet Quantity Requirements

3.2.1. Land suitability evaluation.

According to the relevant literature on the location of public toilets and the information visited by tourists from Xuanwu Lake, this paper regards service efficiency, traffic convenience and landscape coordination as the influencing factors of the layout of public toilets, and subdivides them into several secondary factors, using ArcGIS for single factor evaluation, and converting each evaluation layer into raster images . The main analysis factors are traffic convenience evaluation. The results of land suitability evaluation are obtained by overlapping analysis of public toilet buffer area and scenic spot buffer area. The evaluation results are divided into three levels, of which the evaluation value 3 represents the most suitable for the construction of public toilets, 2 indicates that the construction conditions are more suitable, and 1 indicates that it can be constructed, but there is no suggestion for the construction here (Figure.4).
Table 1. Density of public toilets based on the nature of land use.

| Types of Urban Land Use                                      | Setting density (seat/ km²) | Setting Spacing(m) |
|-------------------------------------------------------------|----------------------------|--------------------|
| Residential land (R)                                        | 3-5                        | 500-800            |
| Public Management and Public Service (A), Facilities Land for Commercial Services (B) | 4-11                       | 300-500            |
| Land for Transportation Facilities (S) and Green Space (G) | 5-6                        | ——                 |
| Industrial (M), Warehousing (W), Utilities Land (U)         | 1-2                        | 800-1000           |

(1) Service efficiency analysis: Firstly, the nature evaluation of park land use, Xuanwu Lake Park land use types are divided into five categories, including waters, roads, landscape architecture, landscape pavement, green space. According to the distribution pattern of scenic spots in Xuanwu Lake Park and the norms of landscape protection in Xuanwu Lake Park (Xuanwu Lake Management Office), this paper chooses landscape paving land and green space as the main land types for public toilet site selection. Secondly, the five-minute walking distance will evaluate the scenic spot buffer zone and the entrance buffer zone. At present, 200m, 300m and 500m buffer zones will be established at the existing park scenic spots and entrances, so that the best walking time is 5 minutes to the nearest public toilet, followed by 8 minutes and 10 minutes [30,31] to the adjacent public toilet (Table 1). At the same time, attention should be paid to the establishment of the distance buffer zone between the current toilets and the current toilets (Table 2). In addition, because the overall terrain of Xuanwu Lake is relatively flat, which basically meets the terrain requirements of the construction of public toilets, there is no evaluation here.

Table 2. Classification and Value Assignment of Influencing Factors for Location and Layout of Public Toilets in Xuanwu Lake Park.

| Category of factors                     | Factor                  | Grading factor | Factor Correspondence Evaluation Value |
|-----------------------------------------|-------------------------|----------------|----------------------------------------|
| service efficiency                      | Nature of land use      | Paving land    | 2                                      |
|                                        | Greenland               | 1              |                                        |
|                                        | Agglomeration degree    | Concentrated   | 3                                      |
|                                        | of human flow           | More intensive | 2                                      |
|                                        | Sparse                  | 1              |                                        |
|                                        | Close to scenic spots   | Far away (500m)| 1                                      |
|                                        |                         | Nearer (300m)  | 2                                      |
|                                        |                         | Near (200m)    | 3                                      |
|                                        | Close to the entrance   | Far away (500m)| 1                                      |
|                                        | and exit                | Nearer (300m)  | 2                                      |
|                                        |                         | Near (200m)    | 3                                      |
|                                        | Distance from current   | Far away (500m)| 1                                      |
|                                        | public toilets          | Nearer (300m)  | 2                                      |
|                                        |                         | Near (200m)    | 3                                      |
|                                        | Convenience of traffic  | Close to the main road | 3                                      |
|                                        |                         | First Class Road |                                         |
|                                        |                         | Secondary Road  | 2                                      |
|                                        |                         | Third class road | 1                                      |
|                                        | Landscape coordination  | Line of sight visibility | 2                                      |
|                                        |                         | Visible        | 2                                      |
|                                        |                         | Invisible      | 3                                      |

(2) Traffic Convenience Analysis: The Xuanwu Lake Park Road is divided into three levels to evaluate the buffer area, and the evaluation results are combined with the evaluation level and converted into raster images to obtain the evaluation results of traffic convenience.
(3) Landscape Coordination Analysis: Through ArcGIS Visual Analysis Tool to analyze the line of sight of each scenic spot, excluding the locations that can directly observe and affect the scenic spots. The more concealed location is the preferred location for public toilets.

3.2.2. Preliminary Location Selection of ArcGIS Location Allocation Principle.
According to the results of land suitability evaluation, the land part of Xuanwu Lake Park was allocated by ArcGIS location allocation principle. When allocating the location, delete the land part which is not suitable for the location of public toilets, including buildings, roads, waters, etc. On the basis of road traffic network data set, the location is selected to maximize the coverage, and 30 initial location points are finally obtained (Figure 4). The service area tool is used to analyze the coverage of the location point to the park area, and combined with the analysis of the human flow data, the related data is derived as the basic data for the optimization of the plan. According to the preliminary calculation, 30 public toilets can meet the needs of public toilets in the park.

![Figure 4. Land Suitability Assessment Results and N Points.](image)

3.3. Selection of Optimal Upgrading Facilities under Optimal Economic Conditions

3.3.1. MATLAB Basic Data Acquisition.
Considering the travel time of Xuanwu Lake Park, after many investigations, it is found that Xuanwu Lake Park is a time point with a larger flow of tourists at 3 p.m. and that the distribution of the flow of tourists on weekends is quite different from that on weekdays. The Xuanwu Lake Park was acquired from Friday to Sunday at 3 p.m. by WeChat (China's popular instant messaging software). Distribution of human flow. By visualizing the data through ArcGIS, we can find that Yingzhou, Huanzhou, Lingzhou, Lover Garden and cruise ship wharf are the most popular scenic spots in Xuanwu Lake Park.

| Information Point | Information Point Equivalent Flow Data |
|-------------------|---------------------------------------|
| 1                 | 46.68559                              |
| 2                 | 54.7696                               |
| 3                 | 59.77798                              |
| ...               | ...                                   |
| 7937              | 286.7189                              |
| 7938              | 47.83271                              |
| 7939              | 53.572                                |

According to the acquired heat of human flow, information points and corresponding human flow information are obtained after GIS processing (Table 3). A total of 7939 information points correspond to the number of different human flows respectively. Connecting it with the initial facilities, we can observe the flow of people and the coverage of the area of each toilet location (Table 4).
Table 4. Information Points Corresponding to Facilities Point Coverage.

| Information Point | Corresponding Facility Point Number | Information Point Equivalent Flow Data | Coverage of corresponding facilities |
|-------------------|-------------------------------------|----------------------------------------|--------------------------------------|
| 85                | 1                                   | 0                                      | 648857                               |
| 586               | 1                                   | 0                                      | 648857                               |
| 587               | 1                                   | 0                                      | 648857                               |
| ...               | ...                                 | ...                                    | ...                                  |
| 5517              | 5                                   | 61.84824                               | 195497                               |
| 5520              | 5                                   | 79.40442                               | 195497                               |
| ...               | ...                                 | ...                                    | ...                                  |
| 2604              | 30                                  | 144.871                                | 326885.9                             |

3.3.2. Solve N value.
The purpose of optimizing public toilets for further location planning is mainly to alleviate the pressure of public testing and use in areas with large population, and to have some nursery rooms and gender-free toilets. In order to achieve the goal of optimization and achieve the highest economic benefits, the following constraints should be implemented:

(1) Constraints on human flow coverage: Xuanwu Lake Park has a large area of water, and most of the human flow is concentrated near YingZhou and Lovers Garden scenic spots.
(2) Area Coverage Constraints: Xuanwu Lake Park water area is more than 1/2 of the garden area, and the park's main activities are in the vicinity of couples' gardens and Cherry Island scenic spots.
(3) Distance constraints: According to the previous, the service radius is set to 500m.

In order to satisfy this condition, MATLAB has obtained 8 locations which need to be optimized, and 2496 different selection schemes.

3.3.3. Solving the optimal scheme with n value limit.
Based on the above 2496 schemes, the optimal scheme of the combination of the eight locations is further selected, that is, the scheme that can serve the largest number of people. The results are shown in the figure 6. At the same time, this paper uses the GIS maximum coverage model to solve the results of the maximum pedestrian coverage, and the results are shown in figure 5.

3.4. Summary
The original number of public toilets is 20, The number of which can’t meet the needs of Park visitors; after location allocation, 30 basic locations are obtained, which can basically meet the needs of tourists, and its service scope can basically cover the whole park's land accessible area.

Among them, Figure 5 is the result of optimizing the location of the highest human flow coverage based on the maximum area coverage of GIS, and figure 6 is the result of the calculation of the
parameters of MATLAB. Among them, the former scheme focuses on the vicinity of the Cherry Island scenic spot, which is insufficient in terms of the coverage of human flow and area, ignoring the coverage of human flow in the northern part of the site and the area coverage of the whole park. The latter is more evenly distributed throughout the garden, which not only meets the needs of human flow coverage, but also takes into account the coverage of the site area.

4. Conclusion
This paper studies the layout and location of public toilets in urban parks. Different from the previous methods of location selection of public toilets in urban parks, this paper introduces the concept of location selection of operational research facilities and refers to the location selection method of maximum coverage model of facility location problem. In the past, GIS was used to evaluate the location of public toilets in urban parks. On the basis of the above, a more scientific, reasonable and accurate layout scheme is designed for the purpose of optimizing economy.

Public toilets are not only the embodiment of tourism service level in urban parks, but also an important carrier of urban civilization. In the planning and design of public toilets in parks, we should not only pay attention to the suitability of the park's land use, but also combine the local folklore, historical and cultural characteristics with the theme of the park, and build a "public toilet-landscape integration" of landscape coordination public toilets, so as to make the layout of public toilets in urban parks more scientific and reasonable.

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