Study on the Assessment of Urban Underground Space Resources: Taking the Main Urban Area of D City as an Example

Shen Zheng[1,a], Yuan Zheng[2*]

realshene@qq.com[a], kinocruz@163.com[*]

[1]Southwest Jiaotong University Chengdu Design Institute Co.,Ltd., Chengdu, China,
[2]National Territory Spatial Planning Research Institute of Sichuan Province, Chengdu, China

Abstract. On the basis of fully analyzing the factors influencing the engineering suitability and comprehensive potential value of the district, this paper takes the main urban area of D city as an example, adopts the calculation principle of hierarchical analysis method, selects scientific underground space resource quality assessment factors, and establishes a comprehensive index evaluation model to assess the comprehensive quality and resource capacity of underground space resources. Promoted Underground space informatization practice, providing powerful means for realizing intelligent control of urban underground space.

Keywords: underground space; resources assessment; hierarchical analysis; fuzzy comprehensive evaluation

1 Introduction

Territorial space planning system of the new era has made clear the general requirement of "adhering to the integration of the development and utilization of aboveground and underground space" and the principle of urban construction of "underground first, aboveground second", reflecting the national level's awareness of the three-dimensional control of national spatial space[1]. The assessment of underground space resources should be a necessary precursor to the preparation of territorial space planning, which directly affects the determination of key indicators such as the development intensity of underground space and the volume ratio, and is also the basis for the scientific, reasonable and moderate development and utilization of underground space resources, and can be used as an important basis for guiding the development, utilization and protection of urban underground space.

The exploration of underground space resource assessment started earlier in foreign countries, and Helsinki City began in the 1990s to comprehensively evaluate the suitability of the city's underground space project construction by analyzing the indicative roles of the geological structure and the degree of bedrock fissure development for the quality of the rock body project[2]. Since 1989, the research on domestic underground space resource assessment has gradually changed from purely assessing the suitability of underground space development to exploring the comprehensive utilization assessment of underground space resources. Since the 21st century, relevant scholars have carried out research on urban underground space resource

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assessment in Beijing, Guangzhou, Qingdao, Xiamen, Guiyang, Wuhan and other cities as well as in the eastern coastal areas, and have constructed a relatively mature underground space development and utilization assessment system[3].

This paper is based on three-dimensional geological structure investigation and model construction, drawing on the research results of perspective underground space, which is a new mode and practice of smart city construction and an inevitable trend of fine utilization of urban underground space.

2 Technical route

Based on the three-dimensional geological structure investigation and model, this paper establishes a scientific and efficient assessment technical route, which comprehensively takes into account the engineering suitability and the comprehensive potential value as major assessment factors, and proposes the underground space resources assessment system combining various influencing factors. Combined with the actual situation of the basic geology of the city, the index elements affecting the development and utilization of underground space are sorted out and screened, and a comprehensive assessment index system for underground space resources is established[4] [5], as shown in Figure 1.

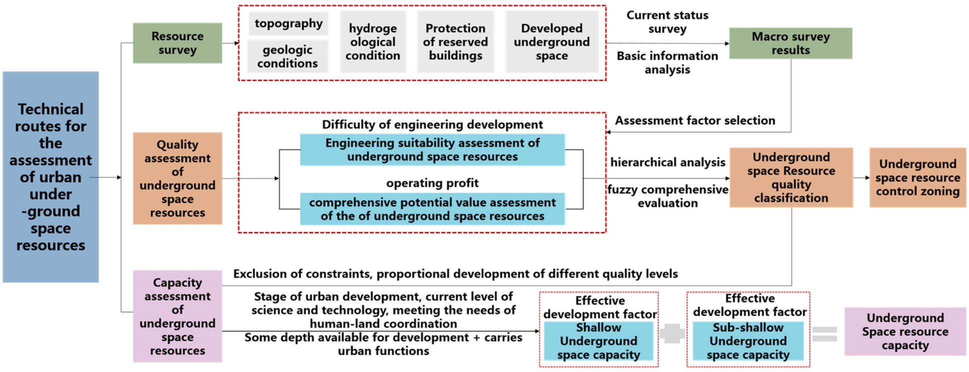


Fig. 1. Technical route of assessment on underground space resources.

3 Evaluation Technical Methods and Processes

3.1 Establishment of Assessment Index System

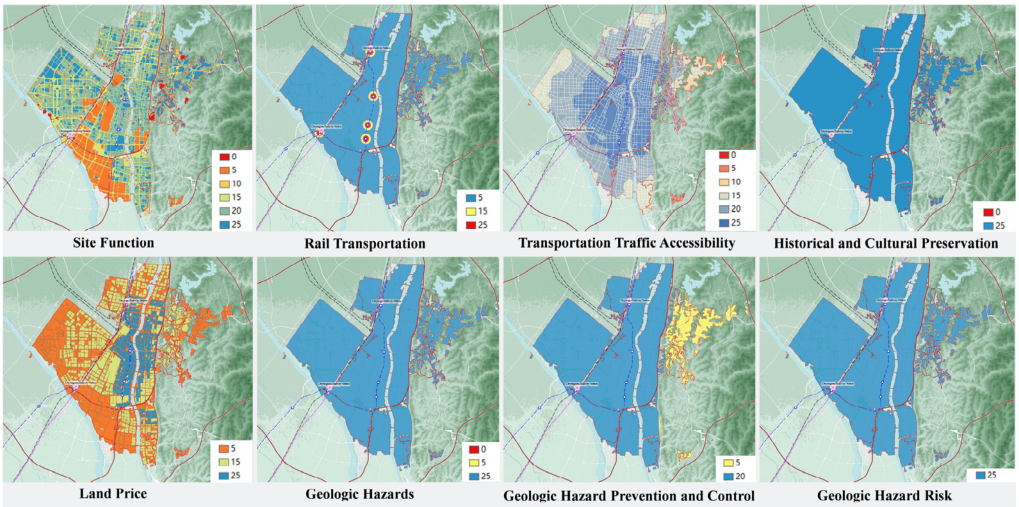
The assessment indexes are divided into two categories: engineering suitability and comprehensive potential value. The engineering suitability takes into account the hard factors such as geologic structure, geologic hazards, geologic hazard prevention and control, geologic hazard risk, and groundwater source protection zone[6] [7]. Comprehensive potential value takes into account soft factors such as land use functions, rail transportation, traffic accessibility, historical and cultural preservation, land price, etc.

This paper refers to relevant empirical studies and adopts a score assignment of 0-25 for assessment. For qualitative indicators that cannot be directly quantified, the expert scoring method is used for assessment. Higher scores indicate lower engineering difficulty and higher comprehensive potential value of the underground space. The values of the indicators are shown in Table 1.

Table 1. List of assessment factors.

Factor	Assignment 0-25
Tectonics	Seismic rupture zones, geological faults within 200m: 0, other areas: 25
Geologic Disaster	Distance to geohazard site, distance ≥100m:25, distance 50-100m:5, distance ≤50:0
Geologic Hazard Prevention and Control	General control areas: 20, sub-priority areas: 5
Geologic Hazard Risk	Low risk: 25
Groundwater Source Protection Zones	Water source protection areas: 0, other areas: 25
Site Function	Commercial Services, Public Administration and Public Services: 25, Residential: 20, Transportation Land, Green and Open Space: 15, Utilities: 10, Industrial, Mining, Warehousing and Other Land: 5, Land Waters, Special Land: 0
Rail Transportation	With site center, radius ≤ 300m: 25, radius ≤ 500m: 15, other plots: 5
Traffic Accessibility	By length of time spent, 6-8 min:25, 9-10 min:20, 11-12 min:15, 13-14 min:10, 15-16 min:5, ≥16 min:0
Historical and Cultural Preservation	Outside Historic Preservation: 25, Historic Preservation District: 0
Land Price	Public service, commercial service, residential (I, II): 25; public service III, commercial service III, IV, V, residential III, IV, industrial I: 15; public service IV, commercial service VI, residential V, industrial II, III, logistics and warehousing IV, V, industrial restriction zone and other areas: 5

The assessment results of eight factors, including geologic hazards, geologic hazard prevention and control, geologic hazard risk, site function, rail transportation, traffic accessibility, historical and cultural preservation, and land price, are shown in Figure 2, which identifies the degree of influence of single factors on the development and utilization of underground space and provides data support for the calculation of the model.



Site Function

Rail Transportation

Transportation Traffic Accessibility

Historical and Cultural Preservation

Land Price

Geologic Hazards

Geologic Hazard Prevention and Control

Geologic Hazard Risk

Fig. 2. Factor Assessment Diagram.

3.2 Evaluation model calculation

In this paper, the multi-factor comprehensive evaluation method is used for evaluation and calculation. Its mathematical model is[3]:

$$\mathrm{S} = \sum_{h=1}^{p}\left[\sum_{j=1}^{m}\left(\sum_{i=1}^{n} A_i B_i\right) C_j\right] D_K \tag{1}$$

Where: S is the total target score, which can be decomposed into a number of targets such as engineering geological conditions and socio-economic conditions; A_i is the quantitative value of the ith single indicator; B_i is the weight of the ith single indicator; C_j is the weight of the jth sub-theme; D_h is the weight of the hth theme.

The control indexes for the suitability of underground space projects in this paper are shown in Table 1, and their assessment models is:

$$S_d = \alpha \sum_{j=1}^{m} w_j \sum_{k=1}^{n} w_{jk}\, u_{jk} \tag{2}$$

Where: u_{jk} is the value of the kth indicator in the jth indicator layer; w_{jk} is the weight of the kth indicator in the jth indicator layer; w_j is the weight of the jth thematic layer; S_d is the result of the assessment of engineering appropriateness; α is the value discount coefficient. The deeper the depth of the excavation, the greater the difficulty of its construction. The difficulty coefficients corresponding to shallow and sub-shallow layers can be taken as 1 and 0.9 respectively.

The control indicators for the integrated potential value of underground space are shown in Table 1.This paper utilizes a multi-factor weighted average approach with an assessment model:

$$S_e = \alpha \sum_{j=1}^{m} w_j u_j \tag{3}$$

Where: u_j is the value of the jth indicator, w_j is the weight of the jth indicator, S_e is the assessment result of comprehensive potential value, α is the value reduction coefficient, and the deeper the excavation depth is, the smaller the potential value of development is. In this paper, it is assumed that the development value has the tendency to decrease linearly with depth, and the difficulty coefficients corresponding to shallow layer and sub-shallow layer can be taken as 1 and 0.9 respectively.

The quality of subsurface space resources and the overlay calculation through engineering suitability and comprehensive potential value are obtained with the assessment model:

$$\mathrm{S} = w_d S_d + w_e S_e \tag{4}$$

Where: S is the quality assessment value of underground space resources, w_d and w_e are the weights of natural factors and socio-economic factors, respectively; S_d and S_e are the assessment values of engineering suitability and comprehensive potential value, respectively.

In this paper, the hierarchical analysis method (AHP) and the expert survey method are used to obtain the index weights, that is, the expert judgment matrix is optimized by the optimal matrix transfer method, and the optimal transfer matrix that meets the requirements of consistency test is constructed. The final weight vector expression of the group judgment matrix processed by the optimal transfer matrix method is:

$$W^* = \left(\frac{1}{A_1^*}, \ \frac{1}{A_2^*}, \ \ldots, \ \frac{1}{A_n^*}\right) \tag{5}$$

Where: W^* is the weight vector of the optimal transfer matrix, A_i^* is the sum of the elements of the ith column of the optimal transfer matrix ($i = 1，2，\ldots，n$).

The rationality of the evaluation matrix is determined by the matrix consistency test index (CI), which is modeled as[8]:

$$CI = (W^* - 1)/(n - 1) \tag{6}$$

Where: W^* is the weight vector of the optimal transfer matrix, n is the order of the matrix. CI = 0, it means the comparison matrix has complete consistency; CI is close to 0, it has satisfactory consistency; the larger CI is, the more serious inconsistency is.

The scientific nature of the comparison matrix is guaranteed by the consistency ratio. The model is:

$$CR = CI/RI \tag{7}$$

Where: CR is the consistency ratio, if the value of CR is less than 0.1, the comparison matrix is considered to have satisfactory consistency. Random consistency index RI can be obtained by looking up the table 2:

Table 2. List of random consistency index.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Calculated engineering suitability CR = 0.0000＜0.10, comprehensive potential value CR = 0.0780＜0.10, which indicates that the judgment of the weight value of the criterion layer is reliable. The corresponding weight values are shown in Table 3:

Table 3. List of weights of assessment factors.

Target Layer	Standardized Layer	Indicator Layer	Weights
Quality Assessment	Engineering suitability	geologic disaster	0.1500
		geologic hazard prevention and control	0.0500
		geologic hazard risk	0.0500
	Comprehensive potential value	site function	0.1951
		rail transportation	0.3061
		traffic accessibility	0.0623
		historical and cultural preservation	0.1243
		land price	0.0623

3.3 Model calculation results

The results of the model calculations were superimposed and analyzed using software, and the underground space in the assessment area was divided into six quality level areas as shown in Table 4:

Table 4. List of quality area scores by level.

Quality Level	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Value	23-25	20-22	18-19	15-17	12-14	<11

Among them, Grade 1 quality areas are the most suitable for underground space development, and Grade 6 quality areas are the least suitable for underground space development, as shown in Figure 3.

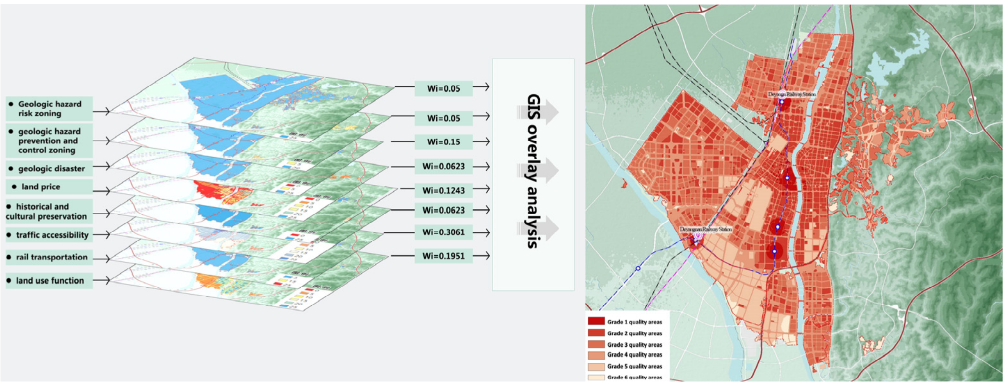


Fig. 3. Quality assessment on underground space resources

3.4 Zoning control of anderground space resources

Based on the assessment of the quality of underground space resources and comprehensively considering the natural geological conditions, ecological environmental protection, historical and cultural protection and other factors, the control zones for the development and utilization of underground space are coordinately delineated as the basis for the planar control of the development and utilization of underground space, i.e., prohibited construction zones, restricted construction zones and suitable construction zones[9], as shown in Figure 4.

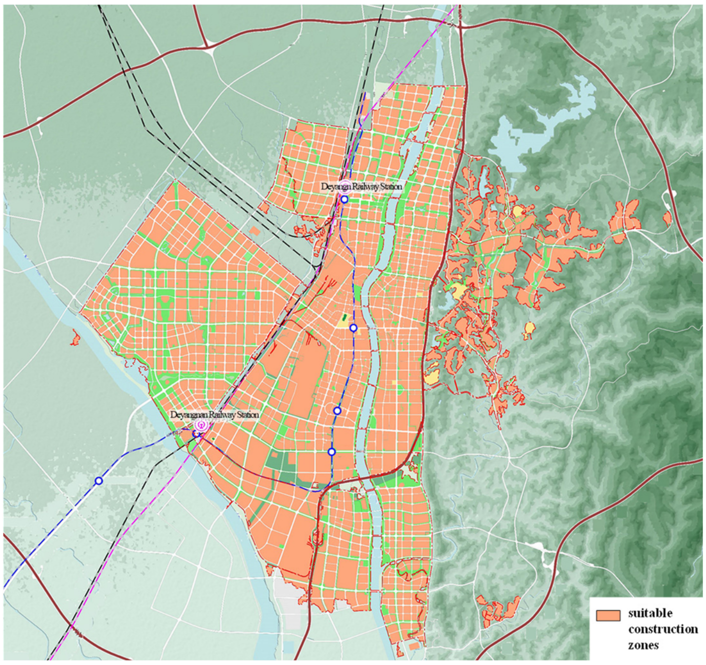


Fig. 4. Control zoning on underground space resources

3.5 Assessment of underground space resource capacity

Based on the basic data of the assessment area, without considering the influence conditions such as the constraints of buildings, safety of urban roadbed, and certain depth required for gardening and greening vegetation, the shallow effective development capacity in the assessment area is 118,864,700 m^2 , and the sub-shallow effective development capacity is 53,225,700 m^2 as shown in Table 5; if we consider the above influencing conditions and refer to the advanced experience at home and abroad, and according to the discount factor of 0.8 for the shallow effective development capacity, the shallow development capacity of D city is 95,000,000 m^2.

Table 5. Statistics on capacity assessment of underground space resources

Rating	Site Area (hm^2)	Percentage (%)	Shallow (0～-15m)		Sub-Shallow (-15～-30m)	
			Factor	Volume(m^2)	Factor	Volume(m^2)
Grade 1	342.82	2.42	0.7	7,199,200	0.5	5,142,300
Grade 2	3014.58	21.30	0.5	45,218,700	0.3	27,131,200
Grade 3	3583.50	25.32	0.3	32,251,500	0.1	10,750,500
Grade 4	4597.31	32.49	0.2	27,583,800	0.05	6,896,000
Grade 5	2203.77	15.57	0.1	6,611,300	0.05	3,305,700
Constraint	409.07	2.89	——	——	——	——
Sum	14151.06	100.00	——	118,864,700	——	53,225,700

4 Conclusion

Through the macroscopic investigation and assessment of underground space resources, comprehensively analyzing and evaluating the state, type, potential and characteristics of the influencing elements of urban underground space resources, and grasps the distribution and change rules of the resources; it is not only the basis for the formulation of a rational, holistic and systematic master plan for the development and protection of urban underground space but also, from the angle of the comprehensive study of natural resources and urban planning, a scientific understanding of the potential and irreversibility of the underground space resources and the provision of a new research and exploration line of thought[10] [11]; it is also the basis for the scientific and rational development of underground space in the main urban area of D City, which is of great significance to the development of urban construction to the comprehensive and three-dimensional space.

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