Study on the Characteristics of Underground Space in Wulong, Chongqing

Wei Li 1,2, Ruigang Zhang 1,2,*, Fei Chen 1,2, Dan Zhou 1,2, Zhen Liu 1,2

1 Chongqing Key Laboratory of Exogenic Mineralization and Mine Environment, Chongqing Institute of Geology and Mineral Resources, Chongqing 400042, China
2 Chongqing Research Center of the State Key Laboratory of Coal Resources of Safe Mining, Chongqing 400042, China

*Corresponding author e-mail: ruigangzhang@cumt.edu.cn

Abstract. Comprehensive study of urban underground space status, efficiently configuring urban underground space resources to serve urban construction. This article selects the integrated analytical system of two levels of engineering geology, hydrological geology, environmental geology and human activities, and draws the weight value of the factor factor weight and the corresponding layer superimposed by one item by item. Sexual distribution. Choosing Chongqing Wulong is a research area, constructs 4 first-level indicators and 11 secondary indicators comprehensive evaluation system, and the factor weight value and adaptation map shows that Wulong Research Area should focus on environmental geological conditions, urban underground space division 3 A total of 12 pieces of zones, and the evaluation results can provide reference for the construction of Wulong city.

Key words: urban planning; adaptability evaluation; AHP; Wulong.

1. Introduction
The adaptability evaluation of underground space was first carried out abroad, and good results have been achieved in solving urban planning and construction and engineering geological problems. An urban underground space development and utilization plan made by Sterling and others in Minneapolis-St. Paul is based on sandstone, and the spatial form and utilization of rock layer, soil layer distribution, hydrogeological distribution, topographical slope and underground space development and utilization are based on sandstone. The suitability and other factors are investigated and analyzed. At the same time, combined with the layout of underground pipelines, underground buildings and above-ground buildings, the impact methods on the development and utilization of underground space resources are classified, and the comprehensive superposition method is used to give the development and utilization of Minneapolis. The distribution scope of the underground space resources and the suitable space form for development and utilization. Based on the engineering geological database, Maurenbrecher analyzed the suitability of tunnel construction in Amsterdam, the Netherlands, and developed topographic and geological thematic maps through the database and geographic procedures to provide a reference for tunnel planning. Ronka et al. examined the status of underground space planning in Finland, investigated the status of use of various underground facilities, and based on this, proposed the classification of
underground space, and established an evaluation model for the suitability of underground space resources in rock formations. DeRienzo and others introduced 3D geological and underground models for the city of Turin based on GIS, and recommended the best plan for the next stage of planning and management of the urban underground space.

A lot of work has been done in domestic research on the suitability evaluation of underground space resources development and utilization. Especially after the 1990s, some suitability evaluation models have appeared in the evaluation of underground space in developed coastal cities.

Wenjun Zhu’s team from Tsinghua University completed the “Survey and Utilization of Shallow Underground Space Resources in Beijing’s Old City”, discussing the influence of geological and hydrological conditions, ground buildings (protected buildings, underground pipelines) and other factors on underground space resources, using remote sensing technology and computers Technically assisted in investigating the status quo of large-scale ground space in the old city of Beijing, classifying it, and determining the relationship with the reasonable development and utilization of underground space resources. Huang Yutian of Beijing University of Technology and others put forward the grey evaluation method to discuss the quality of underground space resources. It is recommended to use six items including the complexity of engineering geological conditions, groundwater conditions, construction technology difficulty, environmental impact, regional importance and comprehensive benefit level. The influencing factors were used as evaluation factors, and a certain analysis was made on the geological background and geological zoning of underground space resources in Beijing. Qingdao Urban Planning and Design Institute and Tsinghua University have perfected the underground space resource survey and evaluation system suitable for hilly and mountainous cities, adopted the evaluation method of resource development difficulty, and established a more complete analytic hierarchy process evaluation index system and model. The suitability and difficulty of rational development of resources are classified and divided.

In the past, underground space adaptability evaluation was mostly focused on a certain type of evaluation element, supplemented by evaluation of other characteristic elements. For example, the underground space adaptability evaluation based on disaster elements gives suggestions for environmental geological conditions; the evaluation based on hydrological conditions gives hydrogeology Condition recommendations; recommendations for engineering geological conditions are given based on the evaluation of the stability of rock formations and slopes. The suggestions and opinions given are highly pertinent and match the characteristics of the study area. It is not easy to copy all of them to other study areas. In fact, it is necessary to build a comprehensive evaluation system based on local conditions and choose a robust evaluation based on the study area’s problems. Means can increase the objectivity and scientificity of the evaluation results.

2. Evaluation method and system construction

2.1. Methods
The adaptability evaluation of underground space development needs to solve the unification and standardization of different attributes, different metrics, and different qualitative and quantitative standards among evaluation indicators. Generally, the overall problem of complex factors should be decomposed and restructured to establish a multi-objective Comprehensive evaluation index system and model, so as to guide and standardize the content and process of underground space resource evaluation, and improve its scientificity as a basis for planning and resource development strategy formulation.

The Analytic Hierarchy Process (AHP) was proposed by American operations researcher A. L. Saaty and others in the 1970s. It is a combination of quantitative and qualitative, systematic and hierarchical multi-objective decision-making methods. It decomposes complex problems into multiple combined elements, forms a multi-level hierarchy according to the dominant relationship, and uses mathematical methods to determine the relative importance of all elements at each level. This method is suitable for problems that are difficult to completely quantitatively analyze, especially when the target element
structure is complex and lacks necessary data. It is more convenient to use. It has been widely promoted and applied in practice. Its calculation formula is as follows.

$$S = \sum_{j=1}^{m} \left( \sum_{i=1}^{n} A_{ij} B_{ij} \right) C_{ij}$$ (1)

In formula (1), S represents the comprehensive score, $S \in [0,1]$, $A_{ij}$ is the quantitative score value of the i-th individual index in the secondary system, $B_{ij}$ is the weight value of the i-th individual index in the secondary system, and $C_{ij}$ is one The j-th index weight value in the level system, $n$ is the total number of second-level indicators, and $m$ is the total number of first-level indicators.

The different contribution rate of indicators to the final result is reflected by weight, which is a concentrated reflection of rationality and objectivity in the evaluation process. Under normal circumstances, the construction of a fuzzy discriminant matrix can determine the weight of each indicator, and the weight scale is to judge the importance of the indicators based on the experience of professionals. The scale value and specific meaning are shown in Table 1.

| Scaling | implication |
|---------|-------------|
| 1       | Indicates that two factors are of equal importance Indicates that compared to two factors |
| 3       | Indicates that two factors are of equal importance Indicates that compared to two factors |
| 5       | Indicates that two factors are of equal importance Indicates that compared to two factors |
| 7       | Indicates that two factors are of equal importance Indicates that compared to two factors |
| 9       | Indicates that two factors are of equal importance Indicates that compared to two factors |
| 2,4,6,8 | Indicates that two factors are of equal importance Indicates that compared to two factors |
| reciprocal | The comparison of factor i and j is judged to get bij, and the comparison of factor j and i, the judgment is $b_{ij}=1/b_{ij}$ |

Consistency testing is a quantification process that effectively avoids large discrepancies in relative weights between indicators. Normally, the testing steps are as follows:

① Calculate the consistency index: $CI = \frac{\lambda_{\text{max}}-n}{n-1}$

Where CI is the consistency index value, $\lambda_{\text{max}}$ is the maximum eigenvalue of the judgment matrix, and n is the order of the matrix.

② Look up the random consistency index RI value table, and the specific parameters are shown in Table 2.

③ Calculate the agreement ratio: $CR = \frac{CI}{RI}$

Generally, when $CR<0.1$, the judgment matrix can be accepted, otherwise the judgment matrix needs to be revised.

| Order n | RI | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---------|----|---|---|---|---|---|---|---|---|---|
| R1      | 0  | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

2.2. Evaluation system construction

In the process of urban planning and construction, it is faced with engineering geological problems, hydrogeological problems, environmental geological problems and avoidance of protection objects, which are aspects that must be considered and taken into account in the evaluation of urban underground space adaptability. The evaluation system indicators are constructed based on the above four aspects and are designated as first-level evaluation indicators, and 11 second-level quantitative evaluation indicators are further refined and determined, as shown in Table 2.

Geological environmental conditions involve topographic and landform indicators that reflect natural geographic conditions, altitude indicators that reflect climate conditions, and disaster indicators that reflect environmental stability conditions; hydrogeological conditions mainly involve water system development indicators that reflect rainfall and precipitation conditions, and rock formations that reflect
rock stability conditions Water permeability index; engineering geological conditions mainly involve the lithological compression index and lithological complexity that reflect the stability of the rock formation; the object of evasion and protection is the red line that cannot be touched or surpassed in the evaluation process, such as protecting farmland, building groups and cultural relics Relic sites should be evaded and protected.

Table 3. Urban underground space adaptability evaluation system

| Target layer | First-level index | Secondary index |
|--------------|------------------|-----------------|
| Environmental geological conditions | Roughness, slope, altitude, Known disaster area | |
| Hydrogeological conditions | Water system development degree, Rock permeability | |
| Engineering geological conditions | Lithology, Lithology | |
| Evasion and protection object | Heritage, Heritage, Heritage | |

3. Index weight determination
The judgment matrix is a method of comparing the importance of the two indicators at the same level. In the first-level evaluation index, the most concerned is the object of avoidance and protection, followed by environmental geological conditions, engineering geological conditions and hydrogeological conditions. Comprehensive expert opinions are based on the first-level evaluation indicators. The relative importance of evaluation indicators constructs a judgment matrix, as shown in Table 3.

Table 4. List of first-level index judgment matrix

| First-level index judgment matrix | Environmental geological conditions | Hydrogeological conditions | Engineering geological conditions | Evasion and protection object |
|----------------------------------|-----------------------------------|---------------------------|---------------------------------|-------------------------------|
| Environmental geological conditions | 1                                 | 2                         | 2                               | 1/3                           |
| Hydrogeological conditions       | 2                                 | 1                         | 2                               | 1/3                           |
| Engineering geological conditions | 2                                 | 2                         | 1                               | 1/3                           |
| Evasion and protection object    | 3                                 | 3                         | 3                               | 1                             |

\[ CI_l = 0.014, \quad RI_l = 0.900, \quad CR = 0.015 < 0.100. \] Therefore, the matrix can be accepted.

Environmental geological conditions: Environmental geological issues are currently the key considerations of government decision-making and scholars' research. The pursuit of harmony between man and nature is the highest goal of all work. Generally, it is embodied by the topography, altitude, climate, hazards and other indicators. The topography and geomorphology conditions can be quantified by two indicators of roughness and slope. The location of the city selects areas with low roughness and small slope; altitude and climate reflect local micro-topography characteristics. In terms of important aspects, urban planning and construction are generally selected at suitable altitudes; hidden hazards are areas that need to be avoided in the process of urban site selection, including historical disasters and existing disasters. Combining the results of environmental and geological adaptability assessments, Prone areas are included in the scope of this study. The areas should be considered and appropriate measures should be taken, such as preventive treatment, evasion and prudent construction.
Hydrogeological conditions: Hydrogeological conditions have been a major consideration in the process of urban planning and management in recent years, involving issues such as sudden flood disasters and geological cutting of water erosion. Generally reflected by two indicators of water system development and rock permeability, the historical highest water level in the Wulong planning area is distinguished as the largest floodplain area, and the area higher than the floodplain area is selected as the optimal location for the city; the rock layer permeability is quantified according to the main lithological characteristics of bedrock, surface water, dissolved pore water, structural fissure water and interlayer fissure water are classified as indicators of geological cutting action of water flow erosion. The city site should be selected for poor lithology and water permeability. Area, can effectively avoid the harm caused by the geological cutting action of water current.

Engineering geological conditions: The site selection of a city first needs to answer the engineering geological conditions. Good basic geological conditions are the fundamental guarantee for the stability of urban buildings. Generally, it is embodied by two indicators of lithological compressive index and rock layer complexity. According to the "Engineering Geological Survey Code" (DBJ50-043-2005) standard, moderately weathered or weakly weathered bedrock is divided into hard rock, soft rock and extremely soft rock. Three standards for rock; taking the number of different lithological strata within a certain range as a quantitative indicator of lithological complexity, it can be roughly divided into three levels: simple areas, general areas and complex areas.

Avoidance and protection objects: The above ground and underground space is always limited in a certain area. Urban planning and site selection are a comprehensive consideration. It requires decision-making which is more important, adhere to the red line of cultivated land protection, key cultural relics protection and important building groups avoidance etc. is the insurmountable red line for the evaluation of urban underground space adaptability. The specific objects include basic farmland and arable land, cultural relics, monitoring sites, large-scale infrastructure construction areas, etc., urban planning areas should be kept away or avoided.

Table 5. Classification criteria of evaluation indexes

| First-level index | Secondary indicators | Suitable zone | More suitable area | General area |
|-------------------|----------------------|---------------|-------------------|-------------|
| Environmental geology | Roughness | Roughness value [0, 2) interval area | Roughness value [2, 4) interval area | Roughness value [4,6) interval area |
| | slope | Slope value [0,10) interval area | Slope value [10,30) interval area | Slope value [30,50) interval area |
| | altitude | Areas below the altitude of 500m | Altitude value 500m-800m area | Areas above 800m above sea level |
| | Known disaster area | 1km outside the disaster area | 0.5km outside the disaster area | 0.1km outside the disaster area |
| | Water system development degree | 1km outside the floodplain | 0.5km outside the floodplain | 0.1km outside the floodplain |
| Hydrogeology | Rock permeability | Outcrop areas of clastic rocks such as sandstone with interlayer water developed in fractures | Shale area with tectonic fissure water | Development of fractured karst cave water carbonate rock area |
| | Lithology compression index | Hard rock outcrops such as carbonate rock and sandstone | Outcrop areas of soft rock such as mudstone and shale | Superficial area with a small amount of loose Quaternary deposits |
| Engineering Geology | Lithological complexity | Two or less different lithological outcrop areas | Two to five different lithological outcrop areas | More than five different lithological outcrop areas |
| Evasion protection object | Heritage site | 1km area outside the reserve | 0.5km area outside the reserve | 0.1km area outside the reserve |
| | Important facilities | 1km area outside the facility area | 0.5km area outside the facility area | 0.1km area outside the facility area |
| | Protect arable land | 1km area outside the farming area | 0.5km area outside the farming area | 0.1km area outside the farming area |
Carry out adaptability evaluation for the underground space of Wulong planning area, comprehensively collect the latest Wulong planning area data, systematically and scientifically formulate an evaluation plan, combine the urban development planning layout of Wulong planning area, and give the optimal urban planning layout plan under the current standards, evaluation. The result is shown in Figure 1.

![Figure 1. The spatial distribution characteristics of urban suitable development zones in Wulong planning area](image)

**Figure 1.** The spatial distribution characteristics of urban suitable development zones in Wulong planning area

4. **Conclusion**

The following conclusions were reached:

1. Construct a comprehensive evaluation system of 4 first-level evaluation indexes and 11 second-level detailed evaluation indexes, including environmental geology, engineering geology, hydrogeology, and protection objects.

2. A total of 3 first-level suitable development zones, with a total area of about 3.010 km², accounting for 2.23% of the total planned area; 4 second-level more suitable development zones, with a total area of about 3.831 km², accounting for 2.09% of the total planned area; 5 a general development zone with a total area of about 6.905 km², accounting for 5.11% of the total area of the planned area.

3. The urban planning and construction of Wulong should focus on the construction of human activities and environmental geological conditions, and the balance between ecological environmental protection and geological disaster prevention and control.

**Acknowledgments**

Fund Project: General Project of Chongqing Natural Science Foundation (cstc2020jcyj-msxmX0941); Geological and Mineral Exploration Project of Chongqing Geological Survey Institute (Yuguizi (2019) No. 128-7).
References

[1] Bai Yunfeng, Zhou Depei. Development characteristics of geological hazards on the banks of Wujiang River from Wulong to Fuling [J]. Journal of Natural Disasters, 2006(05): 7-11.

[2] Hu Xuexiang, Liu Ganbin, Tao Haibing. Research on the suitability evaluation of underground space development in Ningbo based on ArcGIS [J]. Chinese Journal of Underground Space and Engineering, 2016, 12(6): 1439-1444.

[3] Huang Li, Wang Zhimin. Analysis of Research and Development of Urban Underground Space in China [J]. Shanghai Land Resources, 2019, 40(03): 45-51.

[4] Huang Yutian, Zhang Qinxi, Sun Jiale. Discussion on Underground Space Resource Assessment of Beijing Central District [J]. Journal of Beijing University of Technology, 1995(02): 93-99.

[5] Jiang Shengguo, Jiang Siyi, Shi Wenxue, et al. Evaluation of the suitability of shallow underground space in Tianjin Airport Industrial Zone [J]. Mineral Exploration, 2021, 12(02): 446-452.

[6] Lei Guoguang, Sun Yongchao, Li Ming. Analysis based on the development and utilization of urban underground space [J]. Journal of Jilin Jianzhu University, 2015, 32(05): 9-12.

[7] Li Hongchang, Cha Fusheng, Kang Bo. Urban Underground Space Evaluation Index System - Taking Nantong City as an Example [J]. Journal of Hefei University of Technology (Social Science Edition), 2020, 34(05): 113-120.

[8] Li Jing. Evaluation of suitability of underground space development in coastal cities of Fujian based on weighted back analysis [J]. Geology of Fujian, 2020, 39(01): 52-59.

[9] Li Pengyue, Han Haodong, Wang Donghui, et al. Status Quo and Development Trend of Suitability Evaluation of Urban Underground Space Resources Development and Utilization [J/OL]. Sedimentary and Tethyan Geology:1-12 [2021-03-10].

[10] Liu Yunlai, Wu Jiangpeng, Peng Peiyu, et al. Evaluation of suitability of underground space utilization based on geological environment elements [J]. Journal of Yangtze River Scientific Research Institute, 2017, 34(05): 58-62+67.

[11] Ou Xiaoduo, Yang Rongcai, Zhou Dong, et al. Application of AHP method in the suitability evaluation of geological environment for underground space development in Nanning City [J]. Journal of Guilin Institute of Technology, 2009, 29(4): 474-480.

[12] Qin Pinrui, Gao Shuai, Xu Junxiang, et al. Evaluation of suitability for development and utilization of urban underground space resources in Jinan City [J]. Shandong Land Resources, 2019, 35(06): 56-66.

[13] Tan Fei, Wang Jun, Jiao Yuyong, et al. Status quo and trend of research on suitability evaluation of urban underground space at home and abroad [J/OL]. Earth Science:1-13 [2021-03-10].

[14] Tian Yi, Chen Jianping, Wang Limei. Three-dimensional evaluation of the potential resources of underground space in the central urban area of Beijing [J]. China Land Science, 2012, 26(11): 40-44.

[15] Ye Yaobin, Jiang Chunying. Discussion on the development and comprehensive utilization of underground space in Hefei [J]. Anhui Architecture, 2021, 28(01): 29-33.

[16] Zhang Bin, Xu Nengxiang, Dai Chunsen. The status quo, trends and enlightenment of underground space development and utilization in international cities [J]. Earth Science Frontier, 2019, 26(03): 48-56.