Environmental Science and Engineering

Sijing Wang
Runqiu Huang
Rafig Azzam
Vassilis P. Marinos *Editors*

# Engineering Geology for a Habitable Earth: IAEG XIV Congress 2023 Proceedings, Chengdu, China

## Volume 5: Megacity Development and Preservation of Cultural Heritage Engineering Geology

Springer

# Environmental Science and Engineering

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*Editors*
Sijing Wang
Department of Hydraulic Engineering
Tsinghua University
Beijing, China

Rafig Azzam
Department of Engineering Geology
and Hydrogeology
RWTH Aachen University
Aachen, Germany

Runqiu Huang
Chengdu University of Technology
Chengdu, Sichuan, China

Vassilis P. Marinos
School of Civil Engineering
National Technical University of Athens
Zografou, Greece

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# Preface

The XIV Congress of the International Association for Engineering Geology and the Environment (XIV IAEG Congress 2023) was successfully held in Chengdu, China from September 21 to 27, 2023. Focusing on the main theme "Engineering Geology for a Habitable Earth", researchers and practitioners worldwide from academia, industry, and government have joined us in this prestigious event. Based on the topics discussed at the congress, the proceedings are organized into six volumes as follows:

- Volume 1: Engineering Geomechanics of Rock and Soil Masses
- Volume 2: Geohazard Mechanisms, Risk Assessment and Control, Monitoring and Early Warning
- Volume 3: Active Tectonics, Geomorphology, Climate and Geoenvironmental Engineering Geology
- Volume 4: Technological Innovation and Applied for Engineering Geology
- Volume 5: Megacity Development and Preservation of Cultural Heritage Engineering Geology
- Volume 6: Marine and Deep Earth Engineering Geology

Meanwhile, on behalf of the organizing committee, we would also like to express our deepest appreciation to the technical program committee members, reviewers, session chairs, and volunteers for their strong support for congress.

Last but not the least, our gratitude also goes to the editors and press for their great support to the congress.

September 2023 XIV IAEG Congress 2023 Organizing Committee

# Contents

# Chapter 1
# Evaluation of Underground Space Quality for a Delta Coastal City

**Jianxiu Wang, Yuxin Su, Yansheng Deng, Hanmei Wang, Yujin Shi, and Daping Chen**

**Abstract** Underground space resource is an essential part of a delta coastal city. However, complicated underground geological structure and hydro-geological conditions result in different exploitation difficulty and potential disaster. The quality evaluation of underground space resource is significant for both sustainable urban planning and underground engineering. Shanghai was selected as a typical representative of delta coastal cities. A quality evaluation system frame was established, including evaluation index system, evaluation method. Fuzzy method was introduced to determine the grade of underground space quality. The Chenghuang Temple and Zhongshan Park planning units were used as evaluation examples, the quality of shallow, middle and deep underground space resources was evaluated. The evaluation system frame can provide reference for underground space resource evaluation for similar delta coastal cities.

**Keywords** Delta coastal city · Underground space quality · Evaluation system · Urban planning unit · Fuzzy method

## 1.1 Introduction

The urbanization and modernization of delta coastal cities are rapidly because of convenient traffic. In some delta coastal cities, the urban above-ground space cannot meet the requirement of rapid development. The development and utilization of underground space resources have become an inevitable choice. Delta coastal cities

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J. Wang (✉) · Y. Su · Y. Deng
Tongji University, Shanghai, China
e-mail: wang_jianxiu@163.com

Y. Deng
e-mail: dengyansheng@tongji.edu.cn

H. Wang · Y. Shi · D. Chen
Shanghai Institute of Geological Survey, Shanghai, China

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are often located under special engineering geological and hydrogeological conditions. Multi aquifers can induce geological disasters in the process of underground space exploitation. The quality of underground space directly affects the exploitation rate, construction safety, development cost, and environmental influence. The quality of underground space resources usually referred to the comprehensive evaluation of the development and utilization degree of underground space resources, which can be expressed by relative score or grade determined by comprehensive indexes. The quality evaluation of underground space resources can be used as the basis for the supply of potential available underground space resources. The underground space resource quality is influenced by multi factors whose attribute, importance and comparability are not consistent. The quality evaluation of urban underground space resources must consider multiple scales and multiple factors. At present, most of the evaluations depend on subjective experience, establishing quality evaluation system of underground space resources is significant.

The suitability evaluation of underground space development and utilization originated in the early twentieth century in Canada. The characteristics of geological environment were recognized and applied in Germany and other countries in Europe, and the United States to guide the planning and construction of a city. After 1971, a lot of researches were performed on engineering geology in the United States and European. Maurenbrecher and Herbschleb (1994) analyzed the suitability of site selection for tunnel development in Amsterdam based on topographic and geological thematic maps developed by engineering geological database and geographic programming, and obtained results that can provide reference for tunnel construction planning. Rönkä et al. (1998) investigated the use status of various underground facilities and the status of underground space planning, put forward the classification standard that the suitability of underground space development in rock area should be classified according to the construction difficulty, and established the suitability evaluation model suitable for rock area based on this. Canto-Perello et al. (2013) proposed an expert system combining color-coded scales, Delphi and AHP methods to analyze criticality and threats on utility tunnels to support planning of security policies for utilities in urban subsurface. In China, the suitability evaluation of underground space development was first proposed and implemented in Beijing and some coastal cities. Jiang (2019) selected five evaluation indexes by studying the geological environment conditions of Haidian District, Beijing, and AHP was used to construct the evaluation index system of geological environment suitability. Comprehensive index method was used to evaluate the geological environment suitability of underground space development. Ma et al. (2021) proposed the entropy-weight AHP to realize the objective analysis and calculation of weight, and considered account the main geological factors affecting the development of urban underground space and established the evaluation index system by AHP. The proportion of different suitability in the development process of Zhengzhou underground space was obtained. Zhang et al. (2020) selected fourteen evaluation indexes based on the geological environment characteristics of Wenzhou planning area, and calculated the weight of each evaluation index by AHP. The proportion of shallow, middle and deep underground space with different suitability was obtained. Jiang et al. (2019) selected the appropriate evaluation factors by expert scoring method, divided the study area according to the geological environment conditions of each factor, and then determined the weights of each evaluation factor by AHP, and made the suitability evaluation.

In this paper, Shanghai was selected as a typical representative of delta coastal cities. A quality evaluation system frame was established. The grade of underground space quality was determined by using fuzzy method. Zhongshan Park and Chenghuang Temple planning units were selected as two examples whose underground space resources were evaluated. The quality of shallow, middle and deep underground space resources was determined, which can be referred by underground space resource evaluation for a delta coastal city.

## 1.2 Material and Methods

### *1.2.1 Background*

Shanghai was selected as background, and the Zhongshan Park and Chenghuang Temple planning units were used as evaluation samples. In addition to scattered volcanic mounds in the southwest, the bedrock surface is covered by the quaternary system about 250–350 m thick. Due to the small outcrop area of bedrock, engineering geological conditions mainly involve 100 m shallow quaternary loose soil mainly composed of soft soil, silt and clay soil. The shallow sand and silty soil layers (layers ②$_3$, ⑤$_2$ and ⑦ respectively) and soft soil layers (layers ③ and ④ respectively) are closely related to the development and utilization of underground space (Shi 2010).

The phreatic aquifers, micro-confined aquifers and the first, second, third, fourth and fifth confined aquifers (groups) in quaternary unconsolidated sediments exist in Shanghai. The groundwater distributed in the phreatic aquifer, micro-confined aquifer and the first confined aquifer is often called “shallow groundwater” in Shanghai area, while the groundwater distributed in the second, third, fourth and fifth confined aquifers is often called “deep groundwater”. The layers vary in burial distribution, lithologic composition and groundwater formation time.

### *1.2.2 Quality Evaluation Framework*

According to the principle of underground space resource quality evaluation, the quality evaluation frame was established by using AHP method. The actual situation of underground space resource was integrated. The underground space resource quality evaluation index system of recursive hierarchy model was proposed (Fig. 1.1) to ensure the integrity and effectiveness of the evaluation index system.

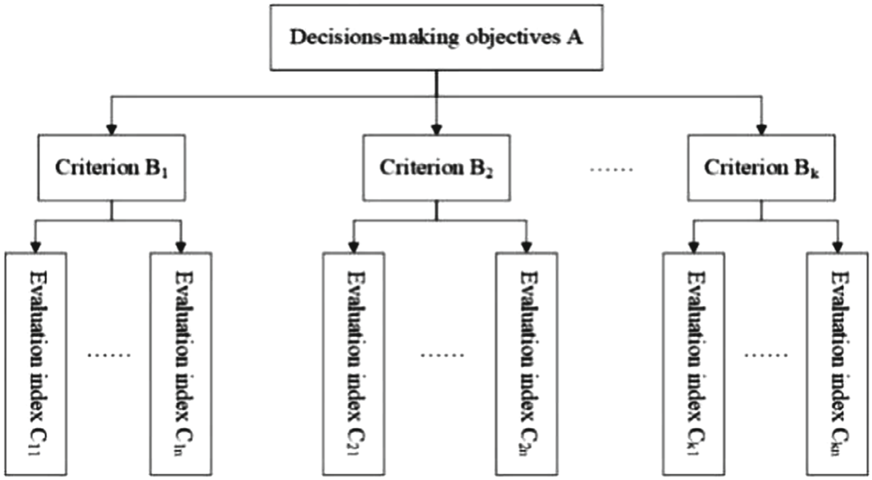

**Fig. 1.1** Regressive hierarchical structure model of underground space resource quality evaluation system

### 1.2.3 Evaluation Index System

Structural stability, engineering geological conditions, hydrogeological conditions, geological disasters, surface buildings, underground space development depth, and other underground resources were taken as the main criteria to determine the quality grade of underground space resources. According to the framework of the evaluation system, the evaluation index system of underground space resources quality was established. The index system was divided into three levels: target layer, criterion layer, and the index layer, as shown in Table 1.1.

### 1.2.4 Evaluation Method

(1) Membership function

Many influencing factors involved in the evaluation of underground space resources quality. Different membership functions should be suggested for different factors and indicators. According to the construction principle of membership function of fuzzy theory, the distribution of membership function mainly included three types: upper type, lower type and middle type with specific functional forms. An appropriate form was selected, and the parameters were determined according to the characteristics of the index and the hierarchical fuzzy set. Quadratic parabolic distribution was adopted in membership function. In combination with the distribution of evaluation indexes, the general form of membership function was revised and improved. The basic form of membership function is shown as

**Table 1.1** Evaluation index system of underground space

| Evaluation target | Evaluation factors | Evaluation factors |
|---|---|---|
| A Quality of underground space resources | B1 Tectonic stability 1 | C1 Basic intensity (level) |
| | | C2 Rate of faulting (mm/a) |
| | | C3 Number of faults and folds |
| | B2 Engineering geological condition 3 | C4 Natural water content (%) |
| | | C5 Void ratio |
| | | C6 Plastic limit |
| | | C7 Compression coefficient ($\mathrm{MPa}^{-1}$) |
| | | C8 Angle of internal friction (°) |
| | | C9 Cohesion (kPa) |
| | | C10 Characteristic value of foundation bearing capacity |
| | B3 Hydrogeological condition 3 | C11 Groundwater level buried deep (m) |
| | | C12 Groundwater level change (H m/a) |
| | | C13 Permeability coefficient (m/d) |
| | | C14 Water inflow per well ($\mathrm{m}^3$/m d) |
| | | C15 Groundwater corrosivity |
| | B4 Geological disasters 2 | C16 Annual settlement rate of land subsidence (mm/a) |
| | | C17 Accumulated settlement (mm) |
| | | C18 Sand liquefaction index |
| | | C19 Land subsidence control area |
| | B5 Building height 4 | C20 Building height (m) |
| | | C21 Floor area ratio |
| | B6 Development depth 4 | C22 Development depth (m) |
| | B7 Underground resources 5 | C23 Geothermal |
| | | C24 Groundwater |

$$\begin{cases} 1 & \left(x \le a_{i,j-1}\right) \\ 1 - 2\left(\frac{a_{i,j-1}-x}{a_{i,j-1}-a_{i,j+1}}\right)^2 & \left(a_{i,j-1} < x \le a_{i,j+1}\right) \\ 2\left(\frac{x-a_{i,j+1}}{a_{i,j-1}-a_{i,j+1}}\right)^2 & \left(a_{i,j-1} < x \le a_{i,j+1}\right) \\ 0 & \left(x > a_{i,j+1}\right) \end{cases} \tag{1.1}$$

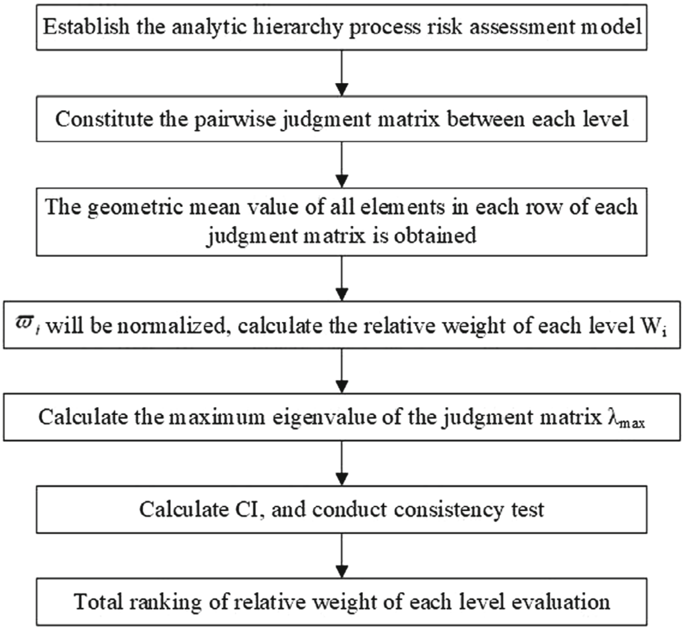

**Fig. 1.2** Risk assessment process of the AHP

(2) Evaluation factor weight

The weight vector of each level index with accurate mathematical model was difficult in calculation because of the complexity and multilevel of the evaluation index system. AHP was used to determine the weight distribution of all the levels of indicators. The process of AHP can be divided into three basic steps: the establishment of model index structure, the determination of judgment matrix, the hierarchical order and consistency test. The risk assessment process of the AHP is shown in Fig. 1.2.

(3) Hierarchical structure model

The problem should be organized and hierarchical to make multi-objective decision using AHP method. The hierarchical structure model should be constructed to reflect the essential attributes and internal relations of the system. In the hierarchical model, the relationship between the system and the environment, the factors contained in the system, the interrelation and membership among factors were determined according to the results of system analysis. The elements with common attributes were merged into a group as a level of the structural model. Elements at the same level acted as constraints on elements at the next level. At the same time, it was restricted by the elements of the upper level. The hierarchical structure model was constructed.

According to the identified risks, the AHP risk assessment model was established. The model included four levels: the total risk target layer, the risk sub-target layer, the partial risk target layer and the risk factor layer.

### (4) Judgment matrix

After the hierarchical structure was constructed, the decision was transformed into the problem of ordering the hierarchical elements. AHP used importance weight as the evaluation index of element ranking. The importance weight was a relative measure with a value between 0 and 1. The larger the value, the more important the element. The importance weight of the lowest level element in relation to the highest level of the overall goal was calculated from the top to the bottom of the hierarchy: first, the single order of the hierarchy, and then the total order of the hierarchy. This process is called hierarchical weight analysis process.

The basis of hierarchical weight analysis was to measure the importance weight of each element in each level with respect to an element in the previous level. The calculation was achieved by constructing a judgment matrix, that is, taking an adjacent element in the upper layer as the criterion, comparing and judging the elements in this layer in pairs, quantifying the comparison results according to specific scoring criteria, and forming a judgment matrix, as shown in Table 1.2. The scoring value represented the importance of the element. The scoring criteria are shown in Table 1.3.

The judgment matrix was constructed by comparing the importance of each element in the lower level of the hierarchy with that of the element in the upper level.

### (5) Order hierarchically and consistency checks

**Table 1.2** Pairwise judgment matrix

| Risk i | Risk j | | | |
|---|---|---|---|---|
| | $A_1$ | $A_2$ | … | $A_n$ |
| $A_1$ | $a_{11}$ | $a_{12}$ | … | $a_{1n}$ |
| $A_2$ | $a_{21}$ | $a_{22}$ | … | $a_{2n}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $A_n$ | $a_{n1}$ | $a_{n2}$ | … | $a_{nn}$ |

**Table 1.3** Evaluation criteria table

| Scale | Meaning |
|---|---|
| 1 | The two factors are of equal importance |
| 3 | One factor is slightly more important than the other |
| 5 | One factor is obviously more important than the other |
| 7 | One factor is highly more important than the other |
| 9 | One factor is extremely more important than the other |
| 2, 4, 6, 8 | The median value of the above two adjacent judgments, such as 2, is between equally important and slightly important |
| Reciprocal | $b_{ij}$ was obtained by comparing factor *i* with factor *j*, and $b_{ji} = 1/b_{ij}$ was obtained by comparing factor *j* with factor *i* |

On the basis of constructing the judgment matrix, the maximum eigenvalue and the corresponding eigenvector of the judgment matrix were calculated. Each component of the eigenvector represented the importance weight of the elements in the hierarchy. The sort was called single sort. Sorting calculation along the hierarchical structure, from top to bottom layer by layer. Root method was a common and effective approximation algorithm. The specific steps were as follows:

(a) Find the geometric average of all elements in each row of the judgment matrix $\varpi_i$

$$\varpi_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \quad i = 1, 2, 3, \ldots, n \ (n\, i\text{s the order of the judgment matrix}) \tag{1.2}$$

(b) $\varpi_i$ was normalized, calculate the weight of the importance of the element in this level that belonged to an element in the previous level $\varpi_i$

$$\omega_i = \frac{\varpi_i}{\sum_{i=1}^{n} \varpi_i} \tag{1.3}$$

(c) Calculate the maximum eigenvalue of the judgment matrix $\lambda_{\max}$

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{n\omega_i} \tag{1.4}$$

where A is the judgment matrix; $w = (\omega_1, \omega_2, \omega_3, \ldots, \omega_n)T$; $(AW)_i$ is the No $i$ element of the vector $(A \cdot W)$.

(d) Consistency test

In order to investigate the consistent of the judgment matrix for the importance of each element, it was necessary to carry out consistency checking in the single ordering of each level. When the consistency ratio was set, the judgment matrix has satisfactory consistency; otherwise, the judgment matrix needs to be adjusted until the test passes.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1.5}$$

$$CR = CI/RI \tag{1.6}$$

where consistency index and average random consistency index can be found in Table 1.4.

(e) Determine the quality level of underground space resources

**Table 1.4** Mean random consistency indicators

| Order number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *RI* | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 |
| Order number | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| *RI* | 1.46 | 1.49 | 1.52 | 1.54 | 1.56 | 1.58 | 1.59 | |

According to the evaluation data of underground space resources quality and the membership function, a single factor evaluation matrix of the index was obtained. According to the fuzzy weight vector A obtained in the previous chapter, the main factor salient operator was used to make fuzzy comprehensive evaluation $B_k = A \cdot R_k$.

Based on the comprehensive evaluation set $B = A \cdot R$ of the first level index, the results were synthesized by the prominent operator of the main factor, and the fuzzy comprehensive evaluation results were analyzed by the maximum membership degree method, then the evaluation level of underground space resources of a certain block was obtained.

The quality level for data acceptance was divided into $V = \{I, II, III, IV\} = \{\text{very good, good, fair, poor}\}$.

Based on the analysis of the factors affecting the quality of urban underground space resources, fuzzy comprehensive evaluation model and membership function were established according to the fuzzy theory, and the weight of each factor was determined by the expert consultation and the analytic hierarchy process, and the classification standard of underground space resources quality was obtained.

## 1.3 Results

### *1.3.1 Zhongshan Park*

Zhongshan Park business District is located on Changning Road, Changning District, Shanghai, with Wuyi Road in the south, Kaixuan Road and Zhongshan Road in the west, Wanhangdu Road in the north, Huayang Road and Anxi Road in the east. It is the sub-center of Shanghai. The area is a combination of tourist attractions, business circles and transportation hubs (Wang et al. 2021).

Zhongshan Park Station is a three line transfer station of Shanghai rail transit Line 3, Line 4 and Line 2 of Subway. With Zhongshan Park Hub station as core, a lot of high grade office buildings around, including Longemont Urban Complex, New Space-time International Business Plaza, Zhaofeng Square, etc. Zhongshan Park subway station has a large number of entrances and exits, so there is a large number of traffic flow. At the same time, as a commercial space, there are also a lot of commercial flow. Therefore, the area needs to develop underground space to alleviate the contradiction between traffic space and commercial space (Fig. 1.3).

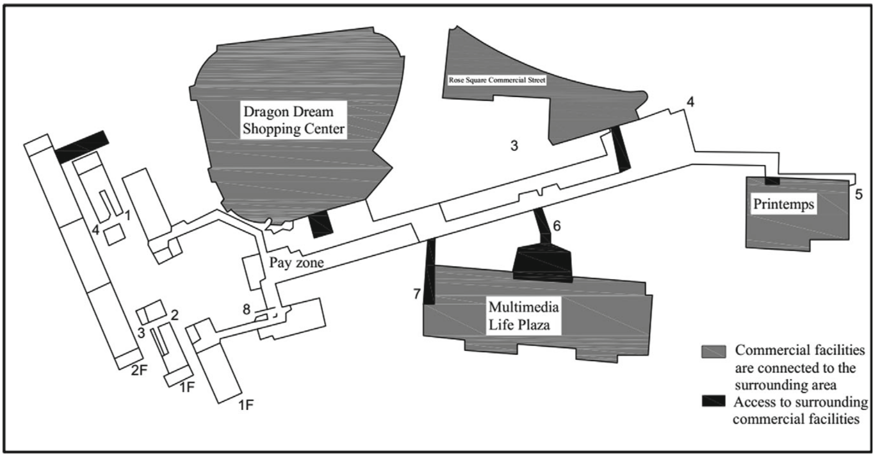

**Fig. 1.3** Schematic diagram of commercial facilities connection around Zhongshan Park hub (citing from the paper: evaluation method of city underground space resources in a delta coastal city)

The evaluation table of underground space resources quality grade of Zhongshan Park planning unit is shown in Table 1.5.

(1) Shallow underground space

The results were synthesized by the dominant factor, prominent operated. The fuzzy comprehensive evaluation results were analyzed by using the maximum membership degree method. The quality evaluation grade of 0–15 m shallow underground space resources in Zhongshan Park planning unit was IV, which was poor.

(2) Middle underground space

The quality evaluation grade of the underground space resources in the middle layer of the Zhongshan Park planning unit from between 15 and 40 m was grade III, which was fair.

(3) Deep underground space

The quality evaluation grade of underground space resources in Zhongshan Park planning unit of 40–75 m was II, which was good.

**Table 1.5** Evaluation table of underground space resources quality grade of Zhongshan Park

| Depth (m) | 0 ~ 15 | | 15 ~ 40 | | 40 ~ 75 | |
|---|---|---|---|---|---|---|
| Quality evaluation | Membership | Level | Membership | Level | Membership | Level |
| | 0.28 | Poor | 0.262 | Fair | 0.267 | Good |

### 1.3.2 Chenghuang Temple

Chenghuang Temple is located at the intersection of Zhonghua Road and Dongmen Road in Huangpu District of Shanghai. It is located in the old town with the most Shanghai characteristics. It is close to the Yu Garden scenic area, with the Bund Financial Center to be built in the north, Zhonghua Road in the east and old residential areas in the southwest. The general plan of Chenghuang Temple Mall is shown in Fig. 1.4.

Chenghuang Temple business district has a large population flow, and its regional functions included tourist attractions, characteristic souvenir shops, characteristic restaurants and characteristic shopping malls. The available space was obviously insufficient.

The quality grade evaluation of underground space resources of Chenghuang Temple planning unit is listed in Table 1.6.

The evaluation grade of underground space resources of 0–15 m block of Zhongshan Park was II, which was good. The quality evaluation grade of underground space resources of 15 ~ 40 m in Zhongshan park plot was grade III, which was normal. The

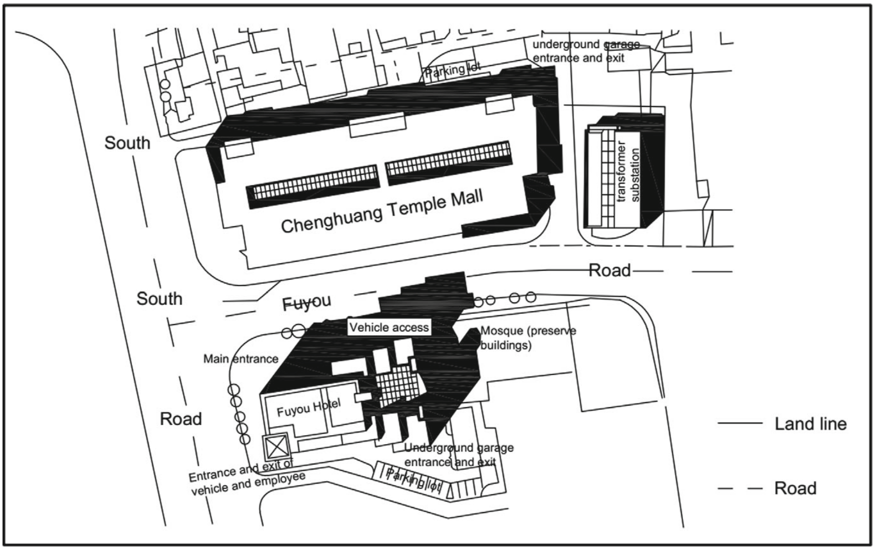

**Fig. 1.4** Chenghuang Temple commercial district spatial structure diagram Shanghai

**Table 1.6** Evaluation table of underground space resources quality grade of Chenghuang Temple

| Depth (m) | 0 ~ 15 | | 15 ~ 40 | | 40 ~ 75 | |
|---|---|---|---|---|---|---|
| Quality evaluation | Membership | Level | Membership | Level | Membership | Level |
| | 0.276 | Good | 0.262 | Fair | 0.267 | Good |

quality evaluation grade of underground space resources in Zhongshan Park block 40 ~ 75 m was II, which was good.

## 1.4 Discussion

The current geological environment was important in the estimation of underground space resources. Further works should be performed in the following aspects:

(1) The regulations on the planning and construction of underground space in Shanghai city have re-stratified the underground space and stipulated the sequence of underground space construction and utilization, so the quality of underground space can be evaluated according to the latest classification of underground space.
(2) From the establishment of hierarchical structure model to the construction of pairwise comparison matrix, human subjective factors play an important role. Moreover, when there are many factors, the workload of analytic hierarchy process is larger. It can be combined with other evaluation methods, such as expert scoring method, to obtain more objective evaluation factors and more concise influencing factors.
(3) The evaluation results can be used in the actual underground space development and utilization to verify the evaluation results. Whether areas of good underground space were fully developed, or simpler construction methods were used, or fewer geological hazards occur.
(4) The evaluation results of underground space quality should actively serve urban disaster prevention and mitigation. In areas with poor underground space quality, construction measures or building structures with greater safety coefficient should be adopted.

## 1.5 Conclusions

The main factors affecting the quality of underground space resources included: structural stability, engineering geological conditions, hydrogeological conditions, geological disasters, surface buildings, underground space development depth, and other underground resources.

The comprehensive evaluation system of underground space resources quality was established. The first level index contains seven influencing elements. The second level indicators were selected to evaluate the first-level indicators.

Fuzzy comprehensive evaluation model and membership function were established according to the fuzzy theory, and the weight of each factor was determined by the expert consultation and the analytic hierarchy process, and the classification standard of underground space resources quality was obtained.

The quality level of underground space resources in Zhongshan Park and Chenghuang Temple demonstration area was obtained. This method can also be used to evaluate the quality of underground space resources in other areas with similar geological environment conditions.

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# Chapter 2
# Evaluation Method of Geological Conditions Suitable for the Development and Utilization of Underground Space in Northern Coastal Bedrock Cities of China

**Jing Zhang, Jian Cui, Changlai Guo, and Yajian Dai**

**Abstract** We selected Jinpu New Area, Dalian as a typical northern bedrock coastal region of China in which to establish a method to evaluate the suitability of geological conditions for underground space development. The geological conditions in Jinpu New Area were studied systematically and five categories of 17 evaluation indices selected. A method of evaluating the suitability of the geological conditions for the development of underground space was established based on an analytical hierarchy process and a multi-objective linear weighting function model. We evaluated the suitability of the shallow (0–15 m), sub-deep (15–30 m) and deep (30–50 m) underground spaces in Jinpu New Area for development. The area with the poor and worst suitability for the development of shallow underground space was 275.2 km$^2$, accounting for 16.1% of the total area. The areas of the sub-deep and deep subsurface areas with poor and worst suitability were 218.85 and 214.82 km$^2$, respectively, accounting for 12.8 and 12.56% of the total area. Goaf, karst and the presence of water aquifers were the main geological problems. This study provides a guide for the evaluation of the geological suitability of the underground space in northern bedrock coastal cities for development and utilization.

**Keywords** Jinpu New Area · Underground space · Geological condition · AHP

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J. Zhang · J. Cui (✉) · C. Guo · Y. Dai
Shenyang Center of China Geological Survey, Shenyang 110034, Liaoning, China
e-mail: spidercj@126.com

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## 2.1 Introduction

The importance of underground space in urban construction was first acknowledged in the 1980s. The Finnish researcher Ylinen (1989) explored the feasible development depth of various urban underground space resources, analyzed the relationships among planning, land use and underground space resources, and proposed a classification system based on the rock area, environmental impact and investment available. Walton and Morfeldt (1981) studied the geotechnical classification of goaf and porous rock storage systems and their influence on the development of underground space. Boivin (1990) considered that earthquakes were the main factor influencing the local development of underground space in Quebec, Canada and was the first person to apply visualization technology in the evaluation of underground space resources, using maps to express information such as the distribution of soil. Edelenbos et al. (1998) described the use of underground space in the Netherlands, the positive and negative influences on the potential use of such spaces and concluded with a strategic study, including the likely prospective applications of subsurface space in the Netherlands.

The efficiency of researching underground space resources has greatly improved with the development of GIS technology. Rienzo et al. (2009) established a 3D geological model of Turin City, which provided a more intuitive and scientific basis for local resource planning, management and the subsequent construction of underground spaces. Bobylev (2010) presented a case study of urban underground space use in an area of Alexanderplatz, Berlin, Germany.

Research on the evaluation of the suitability of underground space for development and utilization started relatively late in China and was first proposed and implemented in Beijing and some coastal cities. Zhu (1992), from Tsinghua University, established the concept, survey method and model system of underground space resources for the first time in China. Tong (2006) discussed the function, constitution and quantification of an index system for the planning of underground space use and put forward a conceptual framework for an index system. An evaluation of the geological suitability of Guangzhou was carried out based on a comprehensive consideration of the main geological factors, such as engineering properties, groundwater depth, and the presence of karst and active faults (Liao et al. 2006). Liu et al. (2011) proposed a comprehensive evaluation model combining the construction status with a geological evaluation and established a suitability evaluation model for the development and utilization of underground space resources in eastern coastal cities of China. The China Geological Survey organized and implemented a large-scale engineering geological survey in the Xiong'an New Area and, taking a typical demonstration area as an example, explored an integrated evaluation method for the suitability of above-ground and underground engineering construction (Hao et al. 2018).

At present, there is no research on evaluation of geological condition suitable for underground space development in northern bedrock coastal cities of China, especially, the evaluation index system suitable for northern bedrock coastal cities has not been formed. We therefore selected Jinpu New Area of Dalian, a typical bedrock coastal region, as the research object and systematically studied the hydrogeology, engineering geology and environmental geology. We selected 17 representative evaluation indices that conformed to the geological characteristics of Jinpu New Area and graded the evaluation standards according to the relevant norms. We established an evaluation system for the geological suitability of underground space based on AHP and a multi-objective linear weighted function model. This evaluation system will provide technical support for the evaluation of the geological suitability of underground space for development and utilization in northern coastal bedrock cities. We evaluated the geological suitability of shallow underground space (0–15 m), sub-deep underground space (15–30 m) and deep underground space (30–50 m) for development and utilization. The evaluation method was verified to be scientific and operable and the evaluation results provided basic data for planning the development and utilization of underground space in Jinpu New Area.

## 2.2 Study Area

Jinpu New Area is located in south-central Dalian city. It is the tenth state-level new area in China and the first state-level new area in the three provinces in the NE of the country. Jinpu New Area includes the whole of Jinzhou District and part of Pulandian District and has a total area of 1969 $km^2$, including a land area of 1710 $km^2$, a salt field and aquaculture area of 146 $km^2$ and a sea area of 113 $km^2$ (Fig. 2.1). With clear geographical advantages and convenient transportation networks, it is the key area of Dalian for future development.

Jinpu New Area is located in the south of the Liaodong Peninsula, an extension of the Qianshan Mountains to the SW, and borders the Bohai Sea to the west and the Yellow Sea to the east. The area forms a hilly terrain between the two seas, characterized by tectonic denudation and hilly landforms. The terrain is complex, with a large relief and a slope of 0–61.7%. The highest point is the main peak of Big Black Mountain in the south, with an altitude of 633.1 m. Tectonically, it is located on the mid-Korean quasi-platform, which is located at the junction of two secondary tectonic units: the Liaodong–Tai Uplift and the North China Fault Depression. The main structural system has an east–west- and NE–NNE-trending structure, with a local NW-trending structure. There are three main faults: the Jinzhou fault, the Pulandian Bay fault and the Dongjiagou fault.

The engineering geological conditions are generally good, although there are some geological problems, such as soil-fill, soft soils, sand liquefaction, mining collapse, seawater intrusion and karst features. The groundwater includes pore waters from loose rocks, karst cave water from carbonate rocks and water from bedrock fissures. The groundwater depth of the river banks and coastal areas is $< 3$ m, whereas that of the other areas is generally 3–25 m. The aquifers in some areas are rich in water and the water inflow of a single well is $> 1000$ $m^3$ $day^{-1}$.

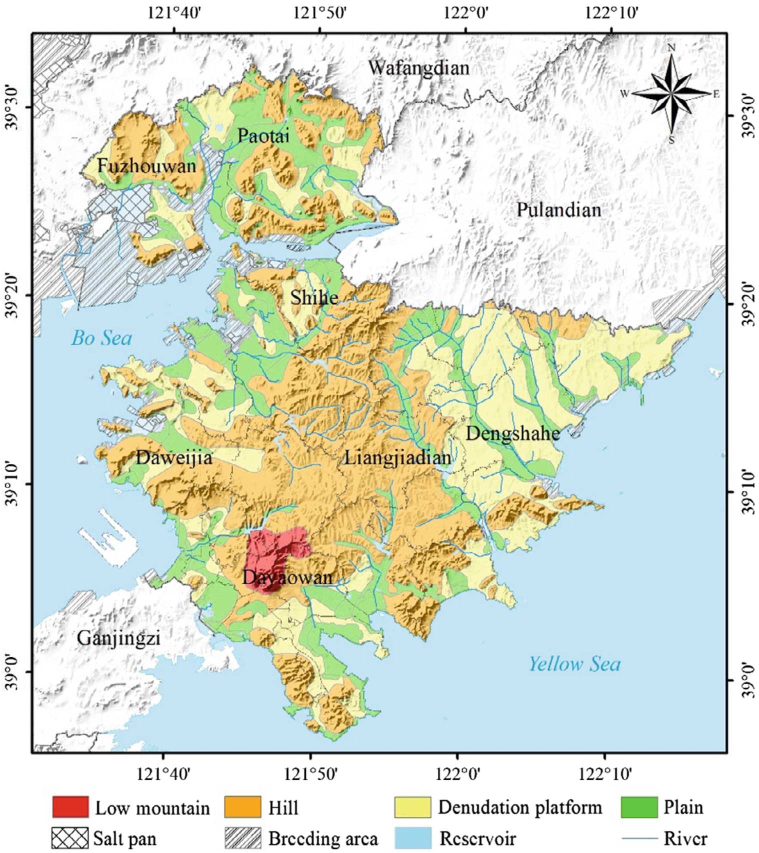

**Fig. 2.1** Geographical of the study area

## 2.3 Materials and Methods

### *2.3.1 Data Acquisition*

To fully support development and planning in Jinpu New Area, the China Geological Survey conducted an investigation into the hydrogeology and engineering geology of Jinpu New Area from 2018 to 2020, with hydrogeological drilling of 992 m, engineering geological drilling of 4038 m, 320 groups of water quality analyses, 150 groups of soil analyses and integrated geophysical well logging to 1580 m depth. These investigations yielded the physical and mechanical parameters of the soil, the underground water level and water quality data and also provided basic data for the evaluation of the engineering geology, hydrogeology, adverse geological effects and soil corrosion.