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An Engineering Geological Suitability Comprehensive Evaluation Index (EGSCEI) for Large-Scale Infrastructure Site Selection

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Abstract

The purpose of this paper is to present a quantitative method to evaluate the engineering geological suitability of potential sites, so as to select the optimal site for large-scale infrastructure. Based on the fuzzy comprehensive evaluation decision method and analytic hierarchy process (AHP), an engineering geological suitability comprehensive evaluation index (EGSCEI) model was proposed, which was applied in the site selection for China initiative Accelerator Driven System (CiADS) and High Intensity heavy-ion Accelerator Facility (HIAF). In this model, seven parameters, including land use, geomorphology, geologic structure, lithology, hydrogeology, geological disaster and rock weathering, were selected as the evaluation factors. The factor evaluation matrices were established, and the weight vector of the seven factors was determined by the AHP. Then, the engineering geological suitability fuzzy comprehensive evaluation vectors were computed. Finally, according to the normalized engineering geological suitability comprehensive evaluation vectors and the quantified evaluation ranks vector, the EGSCEI values were calculated. As a result, site No.3 was evaluated as the most optimal site among the three potential sites for the construction of the CiADS and HIAF. The result was adopted by the Chinese government, and site No. 3 become the selected location. This case study shows that the EGSCEI model is scientific, reasonable and applicable to provide a reference for similar large-scale infrastructure site selection.

Keyword: Fuzzy comprehensive evaluation decision method, Analytic hierarchy process, Site selection, Engineering geological suitability

1. Introduction

Large-scale infrastructure refers to the facility that requires huge capital investment and vast engineering construction to complete. Once completed, it is used to achieve the set goals and tasks through long-term stable and continuous operation (Chen 2014; Chen & Zheng 2015). Affected by factors such as national policies and the shortage of land resources, site selection for large-scale infrastructure is complicated by complex geological conditions and fewer alternative site location options to consider. What’s more, relevant technical standards and engineering analogy experiences are rare in the engineering site selection for large-
scale infrastructure. Therefore, how to scientifically and reasonably carry out engineering site selection is a scientific issue that needs an urgent solution.

Engineering site selection has a long history usually carried out based on existing experience, resulting in a lack of scientificity. While modern engineering site selection originated from an academic paper on warehouse site selection published by Weber (1909). In chronological order, the research on engineering site selection has experienced three stages: scattered research (1909s-1960s), system research (1960s-1980s) and uncertainty research (1980s-present) (Smithies 1941; Hakimi 1964; Mirchandani 1980; Weaver & Church 1983; Yang et al. 2005; Xu et al. 2014; Zhang et al. 2020; Shao et al. 2020). Engineering site selection theoretical models and methods have developed from the early static and deterministic to the current dynamic and uncertain, enhancing the systematic research on uncertain random variables (Cheng & Li 2004; Aksoy & San 2019; Shiokari et al. 2019).

The most commonly used engineering site selection technology is geographic information system (GIS) (Kolekar et al. 2017). With the rapid development of satellite remote sensing technology, GIS is increasingly used in engineering site selection (Osaimi & Qoradi 2020; Santos et al. 2020; Xu et al. 2020). Other commonly used methods include analytic hierarchy process (AHP) (Vasiljevic et al. 2012; Yasser et al. 2013; Guo et al. 2019), analytic network process (ANP) (Isalou et al. 2013; Wu et al. 2018), expert decision support system (Rikalovic et al. 2017), multi-level approximation optimization method (Liu & Hu 1993), multi-constraint analysis technology (Paul et al. 2014), variable weight model (Zhou et al. 2012), entropy weight theory (Zhang & Bao 2005), fuzzy optimization method (Guo & Zhao 2015), multi-factor relationship matrix method (Shang et al. 2000), Delphi method (Du et al. 2019; Deveci et al. 2020), engineering case analogy method (Kuo & Lord 2013), multi-criteria decision analysis method (Cradden et al. 2016; Tsagaratos et al. 2017), community questionnaire survey method (Rojanamon et al. 2009), etc. Among the quantitative evaluation indexes, there are the comprehensive suitability index of the project layout plan (CSI) (Shang et al. 2000), the site sensitivity index (SSI) (Paul et al. 2014), the engineering geological suitability index (EGSI) (Li 2014), etc.

Different large-scale infrastructures have different engineering types and structures, whose distribution characteristics range from point, line to surface, and the requirements for site engineering geological conditions vary. Therefore, the research contents of the site selection for large-scale infrastructure under complex geological conditions mainly include regional stability evaluation, geological structure model, geological hazards distribution, active fault avoidance, unfavorable geological bodies identification, etc. Some famous theories are proposed, for instance, the engineering geological zoning theory (Liu 1959), the safe island theory (Yin 1987), the rock mass structure control theory (Sun 1993), the engineering geologic mass control theory (Liang et al. 1992), etc. However, these theories mainly focus on the geological structure and rock mass structure, turned out to be inadequate. Comprehensively using single factor index method, fuzzy comprehensive evaluation method, artificial neural network method and grey correlation analysis method, Song (2007) established a theoretical system for site selection, by which completed the site selection for the Five-hundred-meter Aperture Spherical radio Telescope (FAST). Based on the multi-factor interaction matrix, the Delphi method and the AHP, Li (2019) proposed an evaluation method for the
engineering site suitability, and carried out site suitability evaluation of the China Spallation Neutron Source (CSNS).

At present, the weight values of the influencing factors involved in the site selection for large-scale infrastructures are difficult to quantitatively determine, resulting in the ambiguity and uncertainty in site selection decision. Subjective factors seriously affect the quantitative value of the suitability of each site to be compared, which makes it difficult to use classical mathematical models to quantify the suitability of the potential sites. In this paper, AHP and fuzzy comprehensive evaluation decision method were applied to large-scale infrastructure site selection and a new engineering geological suitability comprehensive evaluation index (EGSCEI) was proposed. It provides guidance for solving the problem that multiple factors coexist with random and fuzzy information in large-scale infrastructure site selection. In this study, the EGSCEI was used in the site selection for China initiative Accelerator Driven System (CiADS) and High Intensity heavy-ion Accelerator Facility (HIAF), the most advanced high-tech, interdisciplinary fundamental and applied research facilities in the world today.

2. Methodology

The EGSCEI is a mathematical model established based on fuzzy comprehensive evaluation decision method and AHP, which is used to quantitatively evaluate the suitability of the engineering geological conditions of the sites to be compared to determine the optimal site.

Fuzzy sets theory, proposed by Zadeh (1965), marked the birth of fuzzy mathematics, a new branch of mathematics. The basic idea of fuzzy mathematics is using precise mathematical methods to study and deal with fuzzy concepts and fuzzy phenomena. Fuzzy comprehensive evaluation decision method, a multi-factor decision-making method, can make a comprehensive and effective evaluation for things affected by multiple factors. In essence, it is a process of solving the image (comprehensive evaluation result) under the condition that preimage (weight row matrix) and mapping (single factor appraisal matrix) are known. As results, fuzzy and qualitative problems can be converted to quantitative problems. In order to make full use of the information revealed by fuzzy comprehensive evaluation decision method, the author calculates the EGSCEI by multiplying the normalized engineering geological suitability comprehensive evaluation vector with the quantified evaluation ranks vector.

In general, there are mainly five steps to calculate the EGSCEI (Fig. 1): building the evaluation factors set and evaluation ranks set, establishing the factor evaluation matrix, determining the weight vector, computing the fuzzy comprehensive evaluation vector, calculating the EGSCEI.

Fig. 1 Flow chart for the calculation of EGSCEI model

For a site being evaluated by \( n \) indexes, its evaluation factors set can be expressed as \( U = \{ u_1, u_2, \ldots, u_n \} \). If there are \( m \) possible evaluation ranks for each evaluation factor, the evaluation ranks set can be expressed as \( V = \{ v_j, v_2, \ldots, v_j, \ldots, v_m \} \).

Assume the membership of the evaluation factor \( u_i \) to the evaluation rank \( v_j \) is \( r_{ij} \), and the membership of evaluation factor \( u_i \) to all the evaluation ranks is \( r_i = (r_{ij}, r_{i2}, \ldots, r_{im}) \). Therefore, the factor evaluation matrix \( R \) can be expressed as Eq. (1):
The weight vector shows the importance of each evaluation factor with respect to the evaluation of a site. Assume the importance of the evaluation factor $u_i$ is $w_i$, the weight vector can be presented as $W = (w_1, w_2, \ldots, w_i, \ldots, w_n)$ with the boundary condition of $\sum_{i=1}^{n} w_i = 1$. In this study, the AHP method was employed, which is a qualitative and quantitative multi-criteria decision making method proposed by Professor Saaty (1980). This method is concise, flexible and practical, and it can transform qualitative and semi-quantitative problems into quantitative ones effectively. The procedure of the AHP method mainly includes four steps: establishing the analytic hierarchical model, constructing the judgement matrix, single hierarchical ordering and consistency checking, and total hierarchical ordering and consistency checking. When the random consistency ratio is less than 0.1, it indicates that the hierarchical ordering has good consistency, and the weight vector $W$ is acceptable. Otherwise, appropriate adjustments need to be made.

The engineering geological suitability fuzzy comprehensive evaluation vector $B$ is calculated from the weight vector $W$ and the factor evaluation matrix $R$ by using the weighted average model, expressed as Eq. (2) and Eq. (3):

$$ B = W \cdot R = (b_1, b_2, \ldots, b_j, \ldots, b_m) $$

$$ b_j = \sum_{i=1}^{n} w_i r_{ij} \text{ (} j = 1, 2, \ldots, m \text{)} $$

In order to make full use of the information revealed, firstly, normalize the above result $B$ to obtain the normalized engineering geological suitability comprehensive evaluation vector $B'$, showed as Eq. (4) and Eq. (5):

$$ B' = (b_{1}', b_{2}', \ldots, b_{j}', \ldots, b_{m}') $$

$$ b_{j}' = \frac{b_j}{\sum_{i=1}^{n} b_{i}'} \text{ (} j = 1, 2, \ldots, m \text{)} $$

where, $k'$ is positive real number, selected according to different purposes.

Moreover, use the 1-point grading system to deal with the evaluation ranks set $V$ to get quantified evaluation ranks vector $V'$, showed as Eq. (6):

$$ V' = (v_{1}', v_{2}', \ldots, v_{j}', \ldots, v_{m}') $$

Finally, the EGSCEI is calculated by multiplying the normalized engineering geological suitability comprehensive evaluation vector $B'$ with the quantified evaluation ranks vector $V'$, expressed as Eq. (7):
According to the above five steps, the EGSCEI of each site to be compared can be calculated. The larger the EGSCEI value, the better the site engineering geological suitability, then the most suitable site can be selected.

3. Case Study

The CiADS and HIAF, the most advanced high-tech, interdisciplinary fundamental and applied research facilities in the world today, both belong to the 16 large research infrastructures to preferentially construct during the Twelfth Five-Year Plan of China (2011-2015). In the site selection study stage, three potential sites located at Huangbu Town, Huizhou City, Guangdong Province were proposed (Fig. 2).

Investigation on the engineering geological conditions of the three candidate sites for CiADS and HIAF was conducted by the authors, using engineering geological survey, engineering geophysical exploration and laboratory tests. The topographic features, geological structure conditions, stratum lithology distributions, adverse geological effects and hydrogeological conditions of the three sites were basically obtained. The following paragraphs provide a detailed introduction about applying the EGSCEI model to select the optimal site.

3.1 Building the evaluation factors and evaluation ranks set

To evaluate the engineering geological suitability of the three potential sites, seven evaluation factors including land use, geomorphology, geologic structure, lithology, hydrogeology, geological disaster and rock weathering were selected to compose the evaluation factors set (Table 1). The three sites are in close proximity, so the plate tectonics, seismicity, microclimate, and other factors change slightly among these sites, and hence are not considered as evaluation factors.

Table 1 Preliminary comparison of engineering geological conditions of three potential CiADS and HIAF sites

Land use
The CiADS and HIAF site should pay attention to decreasing destruction of ecological environment and damage to nearby residents as far as possible. Therefore, the smaller the site area, the better the suitability, and forest land is more suitable than farm land and orchard. Meanwhile, the existence of residential areas can seriously reduce site suitability.

Geomorphology
It mainly affects the occurrence of geological disasters, the amount of earth works, and the suitability of long-term planning. To be specific, collapse, landslide, and debris flow are more likely to occur in complex topography than flat topography. A good engineering site with simple topography can reduce not only the occurrence of geological disasters but also the amount of earth works for site preparation and infrastructure construction. Furthermore, a suitable site will be conducive to long-term planning also.

Geologic structure
More and more research results show that the stability, deformation, and destruction of a geological body are controlled by the geological structure. In particular, the large-scale active faults have a control effect on
earthquakes and other disasters. The success of geological engineering construction is closely related to the good understanding of the geological structure of the site. Thus, the more complex the geologic structure, the worse the site suitability.

**Lithology**

It is the most basic engineering geological factors, including genesis, age, attitude, degree of metamorphism, and physical and mechanical properties, etc. It is one of the most decisive parameters that determines the stability of rock and soil directly. The physical and mechanical properties decrease gradually from tuff, dacite, andesite to shale. Consequently, the site suitability becomes worse.

**Hydrogeology**

It is an important engineering geological factor for site evaluation. Groundwater is one of the components of a geological body, and it is a significant factor affects the safety of the site. Water-rock interaction exacerbates rock weathering and not only affects the stability of surrounding rock but also induces geological disasters. Therefore, the simpler the hydrogeology, the more suitable the site for construction.

**Geological disaster**

It is a reflection of modern surface geological process, closely related to topography, climate, lithology, structure, and hydrology. It mainly includes landslides, collapses, debris flows, etc., and it is of great significance to evaluate the site stability. The scale and quantity of geological disaster directly affect the safety and economy of engineering construction, thus affecting the suitability of the site.

**Rock weathering**

It directly affects the mechanical strength of the rock. It can not only reduce the stability of the foundation but also induce geological disaster. The weathering crust thickness can reflect the severity of rock weathering, and the thicker the weathering crust, the worse the site stability. So, with the increase of the thickness of the weathering crust, the site suitability decreases correspondingly.

According to the investigation results and the suggestions of the expert team, the suitability of the above evaluation factors for the CiADS and HIAF is divided into four evaluation ranks, including $v_1$ (suitable), $v_2$ (moderately suitable), $v_3$ (poorly suitable) and $v_4$ (unsuitable).

### 3.2 Establishing the factor evaluation matrix

In this case study, a total of 15 experts in the fields of engineering geology and hydrogeology were invited to evaluate the suitability of each factor to the three potential sites by voting. In order to convert the fuzzy and qualitative problem to quantitative problem, the fuzzy statistical method based on the random colony shadow theory proposed by Wang (1983) was used to determine the membership of each evaluation factor to the CiADS and HIAF suitability evaluation ranks. The voting results are shown in Table 2-Table 4.

**Table 2** the voting result for site No. 1

**Table 3** the voting result for site No. 2

**Table 4** the voting result for site No. 3

In this paper the number of votes that experts agree the evaluation factor $u_i$ belonging to the evaluation rank $v_j$ is denoted by $c_{ij}$. The membership of evaluation factor $u_i$ to the evaluation rank $v_j$ can be
calculated by the equation \( r_i = c_i / \sum_{j=1}^{n} c_j \) \( i = 1, 2, 3, 4, 5, 6, 7 \). Thus, the factor evaluation matrixes \( R_1, R_2, R_3 \) for the three potential sites were established, given below:

\[
R_1 = \begin{bmatrix}
0.33 & 0.47 & 0.20 & 0.00 \\
0.27 & 0.33 & 0.27 & 0.13 \\
0.00 & 0.27 & 0.47 & 0.27 \\
0.47 & 0.33 & 0.20 & 0.00 \\
0.67 & 0.20 & 0.13 & 0.00 \\
0.33 & 0.33 & 0.27 & 0.07 \\
\end{bmatrix},
\]

\[
R_2 = \begin{bmatrix}
0.40 & 0.53 & 0.07 & 0.00 \\
0.00 & 0.20 & 0.27 & 0.53 \\
0.00 & 0.13 & 0.47 & 0.40 \\
0.47 & 0.33 & 0.20 & 0.00 \\
0.73 & 0.20 & 0.07 & 0.00 \\
0.47 & 0.33 & 0.13 & 0.07 \\
\end{bmatrix},
\]

\[
R_3 = \begin{bmatrix}
0.53 & 0.47 & 0.00 & 0.00 \\
0.67 & 0.33 & 0.00 & 0.00 \\
0.33 & 0.33 & 0.33 & 0.00 \\
0.33 & 0.40 & 0.27 & 0.00 \\
0.67 & 0.27 & 0.07 & 0.00 \\
0.40 & 0.33 & 0.20 & 0.07 \\
\end{bmatrix}.
\]

### 3.3 Determining the weight vector

In this study, the AHP method was employed to determine the weight vector. This method is concise, flexible and practical, and it can transform qualitative and semi-quantitative problems into quantitative ones effectively. Based on the seven evaluation factors, the single analytic hierarchical model was established. Through comparing the importance of each factor to the site engineering geological suitability in pairs, the judgement matrix \( A \) was constructed:

\[
A = \begin{bmatrix}
1 & 1/3 & 1/5 & 1/4 & 1 & 1/2 & 2 \\
3 & 1 & 1/3 & 1/2 & 3 & 1 & 4 \\
5 & 3 & 1 & 2 & 5 & 2 & 4 \\
4 & 2 & 1/2 & 1 & 2 & 1 & 2 \\
1 & 1/3 & 1/5 & 1/2 & 1 & 1 & 1/2 \\
2 & 1 & 1/2 & 1 & 1 & 1 & 1 \\
1/2 & 1/4 & 1/4 & 1/2 & 2 & 1 & 1 \\
\end{bmatrix}.
\]

The principle eigenvalue of judgement matrix \( A \) \( (\lambda_A) \) and the corresponding eigenvector \( (W_A) \) were then calculated:

\[
\lambda_A = 7.48
\]

\[
W_A = (0.069, 0.160, 0.320, 0.177, 0.080, 0.123, 0.081)^T
\]

The consistency ratio of matrix \( A \) was 0.06, less than 0.1, which indicates that the hierarchical ordering has good consistency, and the weight vector \( W \) is acceptable, given below:

\[
W = (w_1, w_2, w_3, w_4, w_5, w_6, w_7) = (0.069, 0.160, 0.320, 0.177, 0.080, 0.123, 0.081)
\]

### 3.4 Computing the fuzzy comprehensive evaluation vector

According to the factor evaluation matrixes \( R_1, R_2, R_3 \) and weight vector \( W \), the engineering geological suitability fuzzy comprehensive evaluation vectors \( B_1, B_2, B_3 \) for the three potential sites were then calculated by using the Eq. (2) and Eq. (3), and listed as follows:

\[
B_1 = W \cdot R_1 = (0.278, 0.305, 0.305, 0.112)
\]

\[
B_2 = W \cdot R_2 = (0.280, 0.245, 0.256, 0.219)
\]
According to the maximum membership grade principle, the above engineering geological suitability fuzzy comprehensive evaluation vectors indicate that site No. 1 is moderately suitable or poorly suitable for the construction of the CiADS and HIAF, while both the site No. 2 and site No. 3 are suitable. Therefore, it is unable to select the most optimal site based on the fuzzy comprehensive evaluation result because of its limitation.

3.5 Calculating the EGSCEI

In order to overcome the limitation and make full use of the information revealed by the fuzzy comprehensive evaluation results, the EGSCEI was proposed in this paper, which can be used to further determine the ranking of the engineering geological suitability of different sites.

Firstly, the coefficient \( k \) in Eq. (5) was selected 1, with a purpose to simplify calculation. According to Eq. (4) and Eq. (5), the normalized engineering geological suitability comprehensive evaluation vectors were obtained and listed below:

\[
B'_1 = (0.278, 0.305, 0.305, 0.112)
\]

\[
B'_2 = (0.280, 0.245, 0.256, 0.219)
\]

\[
B'_3 = (0.340, 0.296, 0.252, 0.112)
\]

Secondly, each evaluation rank was given a special value between 0 to 1. The value for \( v_1 \) to \( v_4 \) is 0.25-1.00 with an interval of 0.25, so the quantified evaluation ranks vector \( V' \) could be obtained, given below:

\[
V' = (1.00, 0.75, 0.50, 0.25)^T
\]

Finally, based on the normalized engineering geological suitability comprehensive evaluation vector \( B' \) and the quantified evaluation rank vector \( V' \), the EGSCEI values of the sites can be calculated by applying Eq. (7), shown below:

\[
EGSCEI_1 = B'_1 V' = 0.687
\]

\[
EGSCEI_2 = B'_2 V' = 0.647
\]

\[
EGSCEI_3 = B'_3 V' = 0.716
\]

4. Results

In this case study, the EGSCEI values of three potential sites No. 1 to No. 3, are 0.687, 0.647 and 0.716, respectively. The ranking of the three sites follows the order of No. 3 > No. 1 > No. 2. Since the larger the EGSCEI value, the better the site engineering geological suitability. As consequence, the site No. 3 is the most suitable site for the construction of the CiADS and HIAF among the three potential sites.

The site selection evaluation result was adopted by the Chinese government, and the site No. 3 was recognized as the selected location for CiADS and HIAF. The subsequent detailed geotechnical investigation for site No. 3 was launched in December, 2017. Its groundbreaking was carried out in December 23, 2018 (Fig. 3), and will operate in 2022. This engineering site is very suitable for the CiADS and HIAF building so far (https://news.sciencenet.cn/htmlnews/2020/7/442621.shtm), which proves that the evaluation results
are correct.

Fig. 3 Present situation of construction of the CiADS and HIAF (from Google Earth, 2019/10/15)

5. Conclusion

In this paper, the EGSCEI, a new index through quantitatively evaluating the engineering geological conditions suitability of the potential sites to select the optimal site for large-scale infrastructure, was first proposed based on fuzzy comprehensive evaluation decision method and AHP. Its mathematical model and calculation process for site engineering geological conditions suitability evaluation were established.

This method employs the fuzzy comprehensive evaluation decision method to solve the problem that the multi-factor coexists with the random, uncertainty and fuzzy information in large-scale infrastructure site selection comprehensively and objectively. As results, the fuzzy and qualitative problems are converted to quantitative problems effectively. Moreover, the AHP method is adopted to determine the weight values of the influencing factors involved in large-scale infrastructure site selection. Compared with the traditional variable weighting method, the AHP method is more concise, flexible and practical in the evaluation of the complex relationship between the factors. Moreover, it can transform qualitative and semi-quantitative problems into quantitative ones effectively.

In this case study, for the purpose of evaluating the engineering geological suitability of the three potential sites for the CiADS and HIAF, seven factors such as land use, geomorphology, geologic structure, lithology, hydrogeology, geological disaster and rock weathering were selected as the evaluation factors, and the suitability of the evaluation factors was divided into four possible evaluation ranks, including suitable, moderately suitable, poorly suitable and unsuitable. Based on the factor evaluation matrix established from expert vote and the weight vector determined by AHP method, the engineering geological suitability fuzzy comprehensive evaluation vectors were computed. Finally, the EGSCEI values were calculated by multiplying the normalized engineering geological suitability comprehensive evaluation vectors with the quantified evaluation ranks vector, and site No.3 was selected as the most optimal site for the construction of the CiADS and HIAF. The site selection evaluation result was adopted by the Chinese government, and the site No. 3 was recognized as the selected location for CiADS and HIAF, which shows that the EGSCEI model is scientific, reasonable and applicable.

The EGSCEI model based on fuzzy comprehensive evaluation decision method and AHP cannot only be used for the evaluation of large-scale infrastructure site selection, but also has extensive applicability for the type of evaluation in which different factors coexist with random and fuzzy information, making it a promising and reliable method for similar evaluation.

Acknowledgments

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Author Contributions

All authors were responsible for different parts of this paper. Peng Yang, Yanjun Shang and Yanyan Li conducted field investigations. Peng Yang wrote the whole paper. Yanjun Shang, Yanyan Li and Kun Li
revised the paper.

**Conflicts of Interest**

The authors declare that they have no known conflicts of interest that could have appeared to influence the work reported in this paper.

**References**


Fig. 1 Flow chart for the calculation of EGSCEI model

1. Building the evaluation factors set \((U)\) and evaluation ranks set \((V)\)
2. Establishing factor evaluation matrix \((R)\)
3. Determining the weight vector \((W)\)
4. Computing the fuzzy comprehensive evaluation vector \(B = W \cdot R\)
5. Normalizing the comprehensive evaluation vector \((B')\) and quantifying the evaluation ranks vector
6. Calculating the engineering geological suitability comprehensive evaluation index \(EGSCEI = B'V'\)
Fig. 2 Geology and location map of three potential sites to select
Fig. 3 Present situation of construction of the CiADS and HIAF
<table>
<thead>
<tr>
<th>site</th>
<th>$u_1$</th>
<th>$u_2$</th>
<th>$u_3$</th>
<th>$u_4$</th>
<th>$u_5$</th>
<th>$u_6$</th>
<th>$u_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1 site</td>
<td>Site area 95.3 hm$^2$, mainly forest land, with some farm land and orchard. Residential area (Dakengkou Village) within the site</td>
<td>Altitude 10-200 m, valleys and ridges. Amount of cut 23.5 million m$^3$, amount of fill 6.5 million m$^3$, slope height 100 m. Conductive to long-term planning</td>
<td>Moderately complex, both the HIAF and CIADS moderately affected by faults, the backfill area severely affected by faults</td>
<td>Mainly Tuff. A little dacite, andesite and shale in HIAF area and backfill area</td>
<td>Moderately simple hydrogeological conditions. Mainly northwest-southeast surface watershed, fissure water and pore water.</td>
<td>Groundwater depth 0-30 m, small water flow</td>
<td>Weathered crust thickness 10-70 m for HIAF, 10-60 m for CIADS, and 10-30 m for backfill area</td>
</tr>
<tr>
<td>No.2 site</td>
<td>Site area 95.0 hm$^2$, mainly forest land, with less farm land and orchard. Residential area (Dakengkou Village) within the site</td>
<td>Altitude 10-180 m, valleys and ridges. Amount of cut 20.1 million m$^3$, amount of fill 6.5 million m$^3$, slope height 80 m. Less conducive to long-term planning</td>
<td>Complex, the HIAF moderately affected by faults, both the CIADS and backfill area severely affected by faults</td>
<td>Mainly tuff. A little dacite, andesite and shale in backfill area</td>
<td>Simple hydrogeological conditions. Northwest-southeast surface watershed, fissure water. Groundwater depth 0-20 m, small water flow</td>
<td>Only soil erosion disasters in the south</td>
<td>Weathered crust thickness 10-60 m for both HIAF and CIADS, and 10-30 m for backfill area</td>
</tr>
<tr>
<td>No.3 site</td>
<td>Site area 89.4 hm$^2$, all forest land. No residential area within the site</td>
<td>Altitude 10-200 m, valleys and ridges. Amount of cut 9.8 million m$^3$, amount of fill 9.8 million m$^3$, slope height 70 m. More conducive to long-term planning</td>
<td>Moderately complex, the HIAF, CIADS, and backfill area moderately affected by faults</td>
<td>Mainly tuff. Some dacite, andesite and shale in HIAF area.</td>
<td>Moderately simple hydrogeological conditions. Northwest-southeast surface watershed, fissure water and pore water. Groundwater depth 0-30 m, large water flow</td>
<td>Small-scale landslides in the northwest, northeast, and southeast. Soil erosion disasters in the south</td>
<td>Weathered crust thickness 10-70 m for CIADS, 10-60 m for HIAF, and 20-30 m for backfill area</td>
</tr>
</tbody>
</table>

$u_1$ Land use, $u_2$ Geomorphology, $u_3$ Geologic structure, $u_4$ Lithology, $u_5$ Hydrogeology, $u_6$ Geological disaster, $u_7$ Rock weathering
Table 2 the voting result for No. 1 site

<table>
<thead>
<tr>
<th></th>
<th>U</th>
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<tbody>
<tr>
<td></td>
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<tr>
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<tr>
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<td>5</td>
</tr>
<tr>
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<td>5</td>
</tr>
<tr>
<td>$u_6$</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>$u_7$</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3 the voting result for No. 2 site

<table>
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<tr>
<th>U</th>
<th>V_{1v}</th>
<th>V_{2v}</th>
<th>V_{3v}</th>
<th>V_{4v}</th>
</tr>
</thead>
<tbody>
<tr>
<td>u_1</td>
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<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>u_2</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>8</td>
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<tr>
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<td>6</td>
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<td>5</td>
<td>3</td>
<td>0</td>
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<tr>
<td>u_5</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>u_6</td>
<td>11</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>u_7</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
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</tbody>
</table>

u_i: Land use, u_j: Geomorphology, u_k: Geologic structure, u_l: Lithology, u_m: Hydrogeology, u_n: Geological disaster, u_r: Rock weathering; v_i: suitable, v_l: moderately suitable, v_m: poorly suitable, v_n: unsuitable.
**Table 4** the voting result for No. 3 site

<table>
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<th></th>
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<th>v₂</th>
<th>v₃</th>
<th>v₄</th>
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</thead>
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<td>0</td>
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<tr>
<td>u₂</td>
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<td>0</td>
</tr>
<tr>
<td>u₃</td>
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<td>5</td>
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<tr>
<td>u₆</td>
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<td>1</td>
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<td>3</td>
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</tr>
</tbody>
</table>

*Note: uᵢ Land use, u₂ Geomorphology, u₃ Geologic structure, u₄ Lithology, u₅ Hydrogeology, u₆ Geological disaster, u₇ Rock weathering; v₁ suitable, v₂ moderately suitable, v₃ poorly suitable, v₄ unsuitable.*