Research on the Distribution of Frozen soil in Naqu Region Based on the AHP-Fuzzy Method

Lv Xuehai 1, Qin Chengyun 2*, Liu Teng 2, Chen Zhongguo 1, Yan Jubin 1

1State Grid Sichuan Economic Research Institute (Chengdu Chengdian Electric Power Engineering Design Co. Ltd), Chengdu, Sichuan province, 610059, China
2State Key Laboratory of Geohazard Prevention and Geoenvironment Protection (Chengdu University of Technology), Chengdu, Sichuan province, 610059, China

* Corresponding author’s e-mail: 470370577@qq.com

Abstract. The Central Tibet Power Grid project, a high-level transmission line construction project in the Qinghai-Tibet Plateau, stretches over the Naqu region of Tibet with different types of frozen soil distribution. The design, construction and safe operation of the project are seriously affected by the distribution of frozen soil. Based on elevation data, this paper adopted the AHP-Fuzzy comprehensive numerical model as the theoretical research method to make a statistical analysis of the relevant factors affecting the frozen soil distribution. The research was completed with the help of GIS technology. The results show that the AHP-Fuzzy method is feasible for the study of regional frozen soil distribution; that the elevation and temperature are the main factors controlling the distribution of frozen soil in Naqu area; that the permafrost in Naqu area is mainly distributed in the northwest and southwest regions; that the frozen soil is distributed in the low-altitude areas of the central part; that the degradation of frozen soil has occurred in the eastern part of the country due to the rising temperature. The research results will pave way for the future route planning and design of the tower-based network project.

1. Introduction
Central Tibet power grid project is a high-level transmission line construction project in the Qinghai-Tibet plateau frozen soil region after the Qinghai-Tibet HVDC project. Considering its physical properties such as poor thermal stability, strong hydrothermal activity, and susceptibility to environmental changes, the frozen soil[1] is of vital importance to the engineering design, construction and safe operation. With the rapid development of GIS technology, simulating the spatial distribution of frozen soil has also been developed rapidly. Domestic and foreign scholars have conducted researches on the distribution of frozen soil in Qinghai-Tibet plateau and established various frozen soil distribution models with various empirical and statistical experiences, such as elevation model, equivalent elevation model, and geothermal model. Based on the GIS platform, this paper uses AHP-Fuzzy method to investigate the distribution of frozen soil in Naqu region by adopting AHP-Fuzzy[2] mathematical model as the theoretical research method, digital elevation data as based data and combining frozen soil distribution elevation model with other influencing factors.
2. Overview of the research area and main factors of frozen soil distribution

2.1 Overview of the research area

The Naqu region is located in the northern part of the Tibet Autonomous Region. It is among the Tanggula Mountains, the Nangqing Tanggula Mountains and the Gangdise Mountains, with an average elevation of more than 3000 meters. The terrain of the research area is high in the northwest and low in the southeast, and the northwest of the study area is situated in the remaining vein area of the Nianqingtang Gula Mountains Range where mountain peaks are high and steep, terrain is steep, and the average elevation is up to 5500 meters; the southern part of research area belongs to the intersection of the northern Tibetan Plateau and the eastern Tibetan alpine valley, where terrain is very complicated. The climate type of the whole research area is plateau mountain climate. Its annual average temperature is 0.9~3.3°C. There is no absolute frost-free period through the year. From May to September, the climate is relatively warm, with rainfall accounting for 80% of the whole year. The development of frozen soil is closely related to the climatic conditions distributed in the region.

2.2 Main factors of frozen soil distribution

The factors affecting the existence of frozen soil can be roughly divided into three categories: meteorological-hydrological factors (solar radiation, atmospheric circulation, etc.), geological-geographic factors (latitude, elevation, orientation, slope) and geophysical factors. However, those factors are affecting the frozen soil distribution to different degrees. The temperature reflects the combined effects of radiation, atmospheric circulation, and complex ground conditions, which is the dominant factor restricting the existence of frozen soil and controlling the overall pattern of frozen soil distribution [3].

Based on the empirical-statistical model, the statistical relationship between the existence of frozen soil and the surrounding environmental factors in the Naqu of Tibet is established. The statistical relationship between the main influencing factors and the presence of alpine frozen soil is established by means of the index factor of frozen soil presence, such as elevation, slope, aspect, curvature, radiation, rainfall and the annual average temperature. Then index factor distribution map is built based on GIS platform (Fig2~Fig7).
3. The weight of the influencing factors of frozen soil distribution

Various factors contribute to the distribution of frozen soil. Owing to the non-linear relationship among those factors, it is difficult to describe and solve it accurately by mathematical and mechanical methods. The fuzzy mathematics method, however, can deal with the uncertainty problem well. The weight of each factor is determined with the help of AHP. In the solving process, the whole judgment area is divided into several small cells, then the distribution map of the frozen soil is obtained through fuzzy determination.

3.1 Determination of evaluation index and evaluation criteria

3.1.1 Grading of evaluation indicators

A large number of research results shown that frozen soil can be classified into permafrost and seasonal frozen soil. Comprehensive evaluation set of frozen soil distribution characteristics consists of permafrost, seasonal frozen soil and non-frozen soil, \( V = \{ \text{permafrost}, \text{seasonal frozen soil}, \text{non-frozen soil} \} \), and expressed by I, II, III respectively. By comprehensive analysis, an evaluation index grading system is established (Table1) and evaluation factor set \( S = (\text{elevation, slope, slope aspect, curvature, radiation, rainfall, annual average temperature}) \).

3.1.2 Calculating membership

Membership degree refers to the degree of membership of the factor set to the evaluation set. The main difficulty of determining the membership degree of the factors affecting the distribution of frozen soil lies in the fact that some uncertain factors cannot be quantified. The methods for constructing membership functions are mainly fuzzy statistical methods, multi-phase fuzzy statistical methods, and undetermined coefficient methods \(^4\). In this research, nonlinear membership function undetermined coefficient is used to construct the membership function. First, the evaluation index divided into positive index and negative index. The positive index refers to the existence of frozen soil increases as
the index increases. In contrast, the negative index means the frozen soil does not increase with the increase of the index. Constructing membership functions:

\[ U_A(u) = ae^u + b \]
\[ U_B(u) = cu^{-1} + d \]

\[ U_B(u) = cu^{-1} + d \]  

(1)

\[ a, b, c, d \] are the undetermined coefficients; \( U_A(u) \), \( U_B(u) \) are positive indicators and negative indicators. Calculated membership as shown in Table (1).

### Table 1. The determination of evaluation index and membership degree

| Evaluation index | Classification index | Membership values | Evaluation index | Classification index | Membership values |
|------------------|----------------------|-------------------|------------------|----------------------|-------------------|
| Altitude (m)     | I <6599               | 1                 | I >4             | 0.7                 |
|                  | II 4110~5086         | 0.6               | II 2~4           | 0.6                 |
|                  | III >3102            | 0.2               | III <2           | 0.5                 |
| Slope direction (°) | 315~360              | 0.5               | Slope direction (°) | 0.04~0.34         | 0.3               |
|                  | 135~315              | 0.7               | curvature        | 0.6                 |
|                  | 0~135                | 0.5               | -0.04~0.04       | 0.5                 |
| Radiant quantity (J) | 247741~262507       | 0.8               | Radiant quantity (J) | 438.59~681       | 0.1               |
|                  | 239250~247741        | 0.5               | annual rainfall (mm) | 233~438.59     | 0.4               |
|                  | 229250~239250        | 0.2               | 0~233            | 0.7                 |
| Temperature (℃)  | 0~2.4                | 0                 | Temperature (℃)  | 0.2                 |
|                  | -3~0                 | 0.4               | -3~0             | 0.3                 |
|                  | -17~3                | 0.8               | -17~3            | 0.2                 |

3.2 Determination of evaluation index weight by AHP method

Due to the different role and different degree of importance played by each factor in affecting the distribution of frozen soil, a certain weight should be given to each factor in the comprehensive evaluation. This paper solves the weight problem by AHP model. as the following steps:

3.2.1 Problem modeling and selection of judgment scales

A ladder-like hierarchical model in Figure (8) is established.

According to the characteristics of this study, the importance of various influencing factors is ranked (Table 2), and the judgment matrix is established.

### Table 2. Order of importance of factors affecting frozen soil distribution

| Target layer S | Influence factor importance ranking |
|---------------|------------------------------------|
| Influence factor V | \( V_1 > V_2 > V_3 > V_4 > V_5 > V_6 \) |
3.2.2 Hierarchical single ranking and consistency checking of matrices

The consistency check must be carried out for the obtained consistent or nearly consistent matrix. The row element geometry method is used in this study. The approximate value $W$ of the weight vector and the maximum eigenvalue approximate value $\lambda_{\text{max}}$ of the judgment matrix are solved. Then check it for consistency so as to decide whether correct the deviation of the judgment matrix or not.

$$\lambda_{\text{max}} = \frac{1}{n}(m_1 / w_1 + m_2 / w_2 + ... m_n / w_n)$$

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

$CI$ indicates the degree to which the judgment matrix deviates from consistency. The more close to 0, the better the consistency of the matrix. When $CI<0.1 \text{ and } CR<0.1$, it is considered that the hierarchical analysis achieves satisfactory consistency, in other words, the distribution of weight coefficients is reasonable. Otherwise, it is necessary to adjust the values of the elements of the judgment matrix and redistribute the values of the weight coefficients. $W$ is selected as the weight of the influence degree of $v$. The weight matrix is: $W = (0.19 \ 0.14 \ 0.11 \ 0.12 \ 0.15 \ 0.10 \ 0.17)$.

4. Fuzzy evaluation of frozen soil distribution based on fuzzy method

The weighted average model should be selected for fuzzy evaluation because the distribution of frozen soil is affected by all factors together rather than single or primary-secondary factor. let $Z_j = W_j M(*, \oplus)$. $Z_j$ is the membership degree of each factor evaluation value to the criterion layer, $W_i$ is the weight coefficient, $M(*, \oplus)$ is blurring operator which on behalf of single factors membership. According to the principle of maximum membership $Z = \max_{1 \leq i \leq n} (d_i)$, $d_i$ the grade of existence of frozen soil at this point is the corresponding classification.

Based on the AHP-Fuzzy theory, the map of frozen soil distribution in the study area is obtained through fuzzy analysis and grid calculation module of GIS. As shown in Fig (9). The permafrost in Naqu area is mainly concentrated in high and cold area and high altitude areas.

![Figure 9. Naqu frozen soil zoning map](image)

Nima county in the northwest of research area is the main distribution area of permafrost. Due to the lower elevation and frequent human engineering, the distribution of permafrost and seasonal frozen soil in Seni district, Biru county and Suo county is less than that in Nima county. The area of permafrost in

$$\begin{bmatrix}
1.00 & 1.67 & 2.50 & 2.22 & 1.11 & 2.86 & 0.83 \\
0.60 & 1.00 & 1.49 & 1.33 & 0.83 & 1.72 & 0.71 \\
0.40 & 0.67 & 1.00 & 0.89 & 0.74 & 1.14 & 0.63 \\
0.45 & 0.75 & 1.13 & 1.00 & 0.75 & 1.28 & 0.65 \\
0.90 & 1.20 & 1.35 & 1.33 & 1.00 & 1.43 & 0.91 \\
0.35 & 0.58 & 0.88 & 0.78 & 0.70 & 1.00 & 0.57 \\
1.20 & 1.40 & 1.60 & 1.55 & 1.10 & 1.75 & 1.00
\end{bmatrix}$$
Naqu area is about 113600 square kilometers, accounting for 30.17% of the total area; The seasonal frozen soil area in Naqu is about 244600 square kilometers, accounting for 66.0%, while the non-frozen soil area is smaller than that, about 13800 square kilometers, accounting for 3.72% (Table 3). The distribution of permafrost in the southeastern region of Naqu is relatively small. Seasonal frozen soil is distributed in most areas, and non-frozen soils only occupy a small area. Therefore, the distribution of permafrost should be carefully investigated so as to prevent and control possible permafrost diseases when carrying out human engineering construction.

| Acreage (10^4 Km²) | Acreage proportion (%) |
|---------------------|------------------------|
| Permafrost area     | 11.16                  | 30.172                 |
| Seasonal frozen soil area | 24.46          | 66.10                  |
| Non-frozen soil area | 1.38                   | 3.722                  |

5. Conclusion and Discussion
(1) The results basically accord with the characteristics of frozen soil distribution in Naqu region. It is also proved that GIS and AHP-Fuzzy method has feasibility and practicability in investigating regional frozen soil distribution. AHP-Fuzzy model can overcome the shortcoming of single mathematical model and combine the advantages of different models to obtain a more accurate result.

(2) Temperature and elevation are the main binding factors affecting frozen soil distribution. The permafrost is mainly distributed in the northwest and southwest regions of Naqu region, and the seasonal permafrost is found in the mid-low elevation regions of the central part. The frozen soil has begun to melt in the eastern region due to the rising temperature.

(3) The distribution of frozen soil in that region should be taken into account during the construction of the project. Besides, transmission lines should be planned reasonably, and avoid engineering construction in frozen soil as much as possible. The research results will provide some reference value for the planning and design of the pipeline as well as the site selection of the pylon.

Reference
[1] Cheng Guodong, Wang Shaoling. On the zonation of high-altitude permafrost in Chain [J]. Journal of Glaciology and Geocryology 1982, 4 (2): 12~16.
[2] KOTANI Naoya, KODONO Yukio. A Case Study of Fuzzy Exponential AHP and its Applications[J]. Journal of Biomedical Fuzzy Systems Association, 2008, Vol.10 (1), pp.11-18
[3] LIU Chang-Wang, PEI Fa-Gen, QIU Gen-Gen et al. Permafrost distribution characteristics of northern Mohe basin in Northeast China [J] Geophysical and Geochemical Exploration 2017, 41(6):1204-1214.
[4] CHENG Xuejin. An Overview of Membership Function Generation Methods of Fuzzy Reliability Analysis[J] Modern Machinery. 2009(4):40-42
[5] C.E.Akumu, M. Woods, J.A. Johnson, D.G. Pitt, P.Uhlig, S. McMurray. GIS-fuzzy logic technique in modeling soil depth classes: Using parts of the Clay Belt and Hornepayne region in Ontario, Canada as a case study. Geoderma, Volume 283, 2016: 78-87.