Study on Comprehensive Evaluation of Tunnel Route Scheme Based on GIS

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ABSTRACT

The evaluation of tunnel route needs to consider many factors such as natural environment, geography and geology. How to evaluate tunnel route objectively, fairly and effectively has always been a difficult problem for tunnel route selection specialty. The spatial analysis and visualization based on GIS can show the spatial relationship between the tunnel and the evaluation factors, and can make accurate judgments by analyzing the geographical and geological characteristics of the tunnel location combined with the corresponding evaluation model. Based on this, this paper uses GIS to construct the comprehensive geospatial data set of the tunnel scheme to be evaluated, and constructs the comprehensive evaluation model of the tunnel according to the analytic hierarchy process, etc., and evaluates the tunnel scheme from the angles of geography, geology and humanities, and puts forward a set of comprehensive evaluation method of tunnel route based on GIS, which is mature in technology and easy to operate, and has great reference value for railway route selection.

Keywords: GIS, tunnel, geographic information, spatial analysis, database, tunnel route selection

1. OVERVIEW

Building tunnels and bridges instead of ground lines can minimize the negative impact on local ecological environment during pavement construction and operation, reduce noise pollution and reduce the burden of pavement transportation [1].With the rapid development of traffic construction in China, the scale of tunnel construction is expanding continuously, and the total mileage of operating tunnels shows a rapid growth trend. According to statistics, by the end of 2021, China had built 23,268 road tunnels with a total mileage of 2,469.89 km;; 17,532 railway tunnels have been built with a total mileage of 21,055km. The total mileage of urban rail transit lines in 50 cities in mainland China is 9206.8 km, of which the total mileage of subway tunnels is 7209.7 km [2]. Statistics show that the mileage of tunnel operation in China has ranked first in the world, and great achievements have been made in the construction of traffic tunnels [3]. Among them, tunnel route selection design is a work that needs multi-specialty cooperation. Workers not only need to comprehensively consider the humanistic environment of the tunnel, but also consider the natural environment factors related to the tunnel, such as meteorology, hydrology, geography and geology [4]. Therefore, ensuring the rationality, reliability and accuracy of tunnel route selection method is very important for the smooth construction, quality assurance and safe operation of the project. Based on the above factors, quantitative evaluation of the route scheme is carried out to assist the tunnel to control risks and break through difficulties, which is an important research direction of tunnel route selection [5].

To evaluate whether a tunnel design scheme is reasonable, many factors such as route direction, hydrogeology, environment and ecology should be considered. By analyzing the engineering geological problems in the suture zone of Yarlung Zangbo River, Sharla Cheung et al. put forward the comprehensive geological route selection principle, and decided the optimal scheme according to this principle [5] [6]. According to the tunnel conditions, Chen Jingjun and others studied the route direction, on-off repair and overall construction of the tunnel, and put forward supporting schemes such as mechanization, informationization and emergency evacuation and rescue [7]. According to the environmental characteristics and construction requirements of the tunnel, Li Guoliang et al. discussed the key construction schemes in all aspects, and provided a complete set of design schemes for the prevention and control of

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hard rock burst under high geostress, which further enriched the design technical experience of long and long cross-ridge tunnels under complex natural environment in China [8].

In the process of scheme evaluation, factors such as tunnel stratum, lithology, tunnel water inflow and so on should also be combined. After analyzing the stratum lithology and hydrological characteristics of Regong Crossing Tunnel, Professor Chang Shuaipeng determined the hydrogeological route selection criteria of this section. [9]. By analyzing the rockburst situation of underground construction in China, Ma Junjie and others constructed a geological model for predicting rockburst disaster [10]. By analyzing the hydrogeological conditions in the tunnel and according to the characteristics of the tunnel itself, Zhang Yu and others constructed a comprehensive evaluation model for the selection of tunnel route scheme by using analytic hierarchy process and fuzzy comprehensive evaluation method, and obtained the final result after comprehensive comparison [11].

The above research includes most factors that affect tunnel construction, and uses AHP and fuzzy comprehensive evaluation method to study the rationality of tunnel scheme, and gives a variety of tunnel scheme selection and evaluation schemes, which makes great contributions to the subsequent tunnel route comparison and evaluation. However, there are still some problems in the above research, such as the evaluation results are not intuitive enough, some schemes are difficult to understand, and some schemes are not concise enough. Under the guidance of modern spatial system analysis theory, GIS spatial data analysis function mainly refers to studying spatial problems, constructing analysis simulation models and developing spatial data analysis tools according to spatial structure characteristics. Through this function, the line selection results after superposition of various influencing factors can be clearly and intuitively displayed, which can assist in verifying the line selection scheme and provide demonstration basis for the line selection results [12]. This paper studies the feasibility of tunnel route through the spatial analysis function of GIS, establishes a GIS comprehensive route selection model, supports the results of route selection and station selection from the perspective of comprehensive application of geographic information, and puts forward a set of comprehensive evaluation methods of tunnel route based on GIS. It improves the accuracy and efficiency of the follow-up railway route selection, and saves the cost of manpower and material resources.

2. OVERVIEW OF TUNNEL ROUTE

The tunnel to be evaluated in this paper is about 20735m long and the maximum buried depth is 1219m. The tunnel passes through the mountains and enters the plateau, with an entrance elevation of about 3200m and an exit elevation of about 3750m.

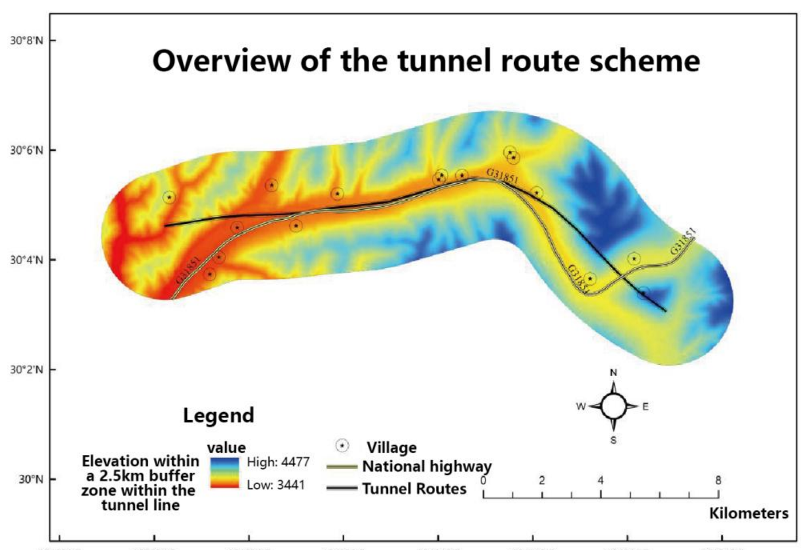

Figure 1. Overview of tunnel scheme

2.1 Topography and geomorphology

Due to the huge tectonic action and the transformation of external power (glaciers and rivers) in the later period, the tunnel has large terrain height difference, dense valleys and vertical and horizontal mountains, but lush forests and warm climate, which has typical characteristics of subtropical air temperature and humidity valley. The surface height is 3460-4730m, and the external force is mainly caused by ice water corrosion, freezing and thawing, accompanied by biological weathering, which is a typical plateau landform [13]. The entrance and exit ends of the tunnel are close to National Highway 318, and the traffic conditions of rural access roads in the entrance section are good, but there is no rural road leading to the exit, and the traffic conditions are average.

2.2 Meteorological characteristics

According to geographical latitude, the tunnel site belongs to subtropical climate, but because it is located in Hengduan Mountain area with high average altitude, it is affected by complicated geomorphic environment, which changes the regional climate development order, resulting in complex and changeable weather, resulting in a unique plateau continental monsoon climate, and only in valley areas with low average altitude, it has slightly subtropical climate characteristics [14].

2.3 Geological structure

In the tunnel area, 119 destructive earthquakes with magnitude not less than 4.7 were recorded. Among them, there were 28 earthquakes of magnitude 4.7 to 4.9, 60 earthquakes of magnitude 5.0 to 5.9, 19 earthquakes of magnitude 6.0 to 6.9, 11 earthquakes of magnitude 7.0 to 7.9 and 1 earthquake of magnitude 8.0. In addition, 13,353 modern small earthquakes (magnitude 2.0 to 4.6) were recorded in the region, including 11,361 earthquakes of magnitude 2.0 to 2.9, 1,669 earthquakes of magnitude 3.0 to 3.9 and 323 earthquakes of magnitude 4.0 to 4.6. The tunnel is located in the joint development zone of deep and large moving faults, and there are many moving faults combined with geese along the mountain direction.

3. TECHNICAL ROUTE AND EVALUATION METHOD

3.2 Technical route

In this paper, the characteristics of the tunnel route to be evaluated are analyzed in terms of topography, geomorphology and hydrogeology, and then the surface analysis of slope, aspect and undulation of the tunnel scheme to be evaluated is carried out by GIS software. Combined with the results of tunnel characteristic analysis and surface analysis, the comprehensive geographical spatial data set is established by using analytic hierarchy process, and the comprehensive evaluation model of tunnel route scheme is formed.

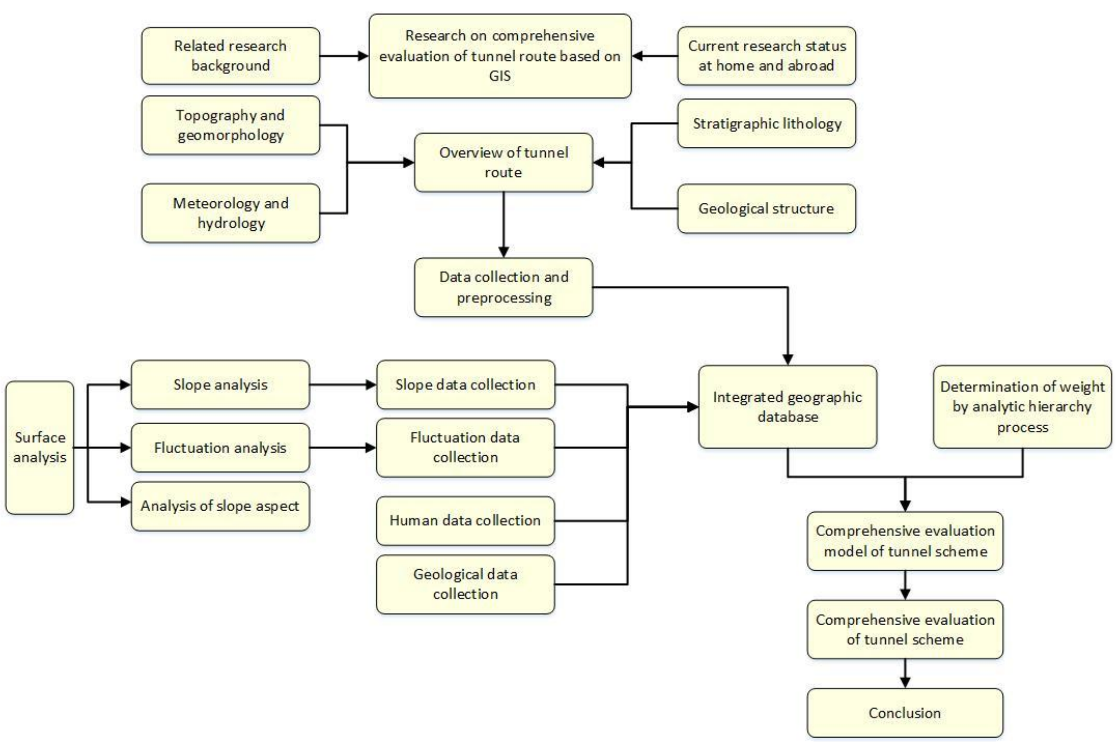

Figure 2. Technology roadmap.

3.2 Surface analysis of tunnel line

In order to obtain the topographic spatial feature information of the tunnel scheme, the surface analysis of the tunnel scheme is carried out, and the main research contents are aspect, gradient, undulation and so on. Raster data structure is simple, operability is high, can support a variety of calculation and analysis, so this study chooses raster data for terrain evaluation factor analysis. Slope is the ratio of height difference and distance within a certain distance, which is very important to the transportation capacity, safety and comfort of locomotives on the line. In principle, we should try our best to choose a gentle slope, which can save fuel and improve transportation capacity. Fluctuation is the elevation difference between the highest point and the lowest point of terrain in the region, which is mainly used to distinguish regional terrain features [15]. To sum up, through the analysis of the slope, aspect and undulation of the line by GIS, the overall and objective evaluation of the topography of the line can be carried out. The research results are shown in the following figure.

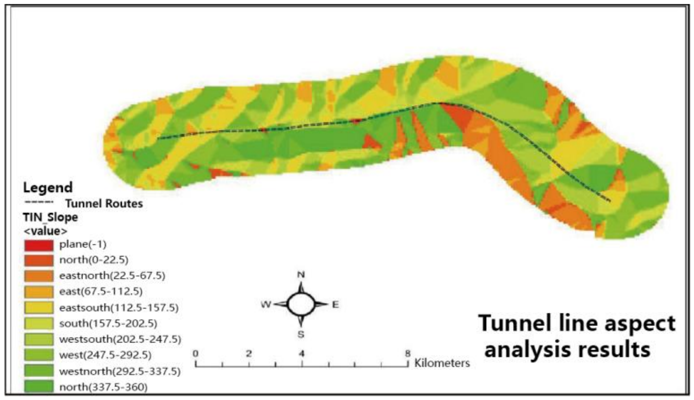

Figure 3. Aspect analysis results of tunnel scheme.

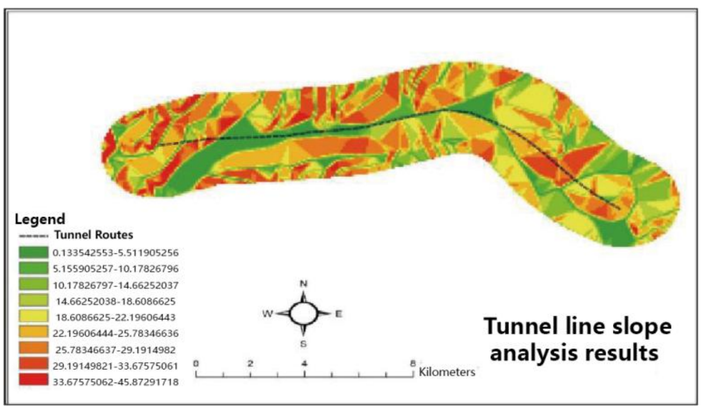

Figure 4. Slope analysis results of tunnel scheme.

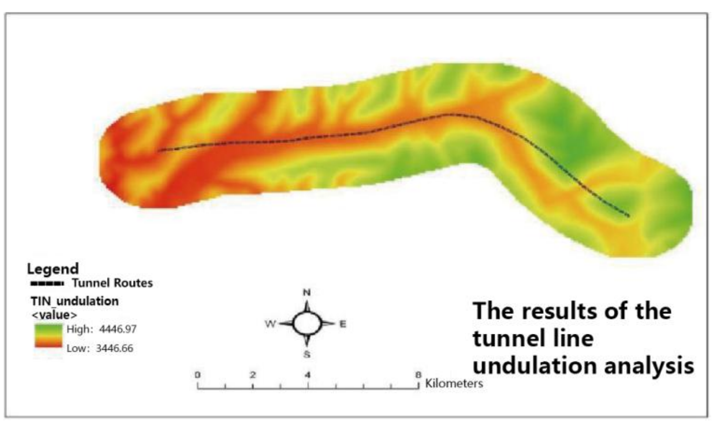

Figure 5. Analysis results of tunnel scheme fluctuation.

3.3 Establish a comprehensive evaluation model

In the above study, the surface analysis of slope, aspect and fluctuation of tunnel line is carried out. Through surface analysis, the topographic characteristics of this area are obtained, but it is not enough to get an objective and comprehensive evaluation result. Therefore, this paper through the establishment of GIS database, and through the GIS database related geographic data management and analysis, complete the fusion analysis of multi-source data, through the analytic hierarchy process for comprehensive evaluation, and finally get the comprehensive evaluation model of tunnel route.

3.3.1 Geographic database

GIS database can classify all kinds of complex time and space data and manage them uniformly. The databases in GIS software include file geographic database and personal geographic database, each of which has its own merits [16]. The storage capacity of file database is much larger than that of personal geographic database, and the storage form is easier to manage. Here, file geographic database is selected for data storage and management.

3.3.2 Analysis of influencing factors of lines

At present, with the further deepening of scientific research in various fields, new multi-objective decision-making modes and schemes are increasingly produced, each of which has its own advantages and disadvantages, and also has relative applicability. This paper mainly considers the optimization of tunnel route scheme from two perspectives of natural geographical factors and geographical-hydrological factors. Because compared with the traditional railway tunnel route selection which focuses on technical and economic index factors, more consideration should be given to the comprehensive hydrological factor selection route, so it is necessary to choose the appropriate way and method according to the special geographical background of the tunnel. Analytic Hierarchy Process (AHP) can efficiently solve complex phenomena that cannot be completely quantitatively analyzed, and can be transformed into both qualitative and quantitative complex phenomena, so that this phenomenon can also be quantitatively analyzed, and through its weight, the deviation and distortion in qualitative analysis can be reduced in a certain sense [17]. Therefore, this study adopts analytic hierarchy process for mathematical analysis.

Traditional route evaluation is generally based on the comprehensive analysis of expert knowledge. This method has great subjectivity. In this paper, ArcGIS software and route evaluation factors are used to analyze the route model, and subjective and objective factors are considered comprehensively, and the optimal route is obtained by calculating the weights of various tunnel route influence factors. There are three steps to judge weights in AHP: establishing hierarchical structure model, constructing judgment matrix and carrying out relative weight measurement experiment. The first is to establish a hierarchical structure model.

Construction of analytic hierarchy process model

In this paper, the analytic hierarchy process model is constructed, and four types of data, such as slope, fluctuation, geology and humanities, are selected as indicators. The hierarchical structure analysis is shown in the figure.

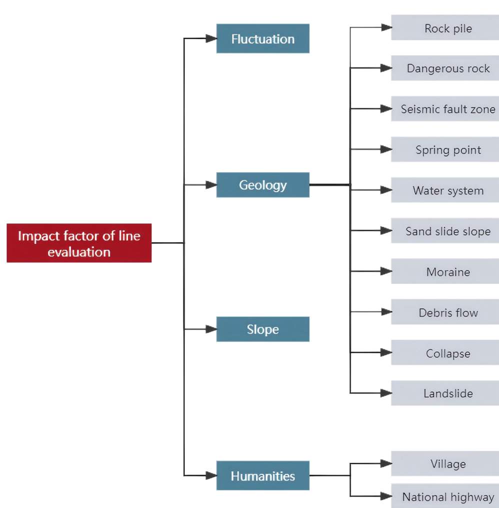

Figure 6. Tunnel Scenario Hierarchy Analysis Structure Diagram

Implementation of Analytic Hierarchy Process Algorithm

Use Excel to calculate the weight of each data set, and the calculation results are shown in Table 2.

Table 1. Construction of Judgment Matrix.

	Geology	Slope	Fluctuation	Humanities
Geology	1	1/4	1/3	2
Slope	4	1	2	5
Fluctuation	3	1/2	1	4
Humanities	1/2	1/5	1/4	1
Σ	8.50	1.95	3.58	12.00

The columns in the matrix table are normalized, and then summed horizontally. After the summed columns are normalized, the relative importance weights of the four factors can be obtained, as shown in the following table.

Table 2. Relative importance weights of four factors.

	Geology	Slope	Fluctuation	Humanities	Σ	Weight
Geology	0.12	0.13	0.09	0.17	0.51	0.13
Slope	0.47	0.51	0.56	0.42	1.96	0.49
Fluctuation	0.35	0.26	0.28	0.33	1.22	0.31
Humanities	0.06	0.10	0.07	0.08	0.31	0.08
Σ					4.00	1.00

Four weights of the criterion layer are obtained from Table 4, which correspond to geological, slope, undulation and human factors: 0.13, 0.49, 0.31 and 0.08 respectively.

3.3.3 Model building

There are many influencing factors of tunnel route evaluation. In order to facilitate analysis, this paper classifies the influencing factors of the tunnel scheme according to the specific characteristics of the tunnel scheme through the database management function of ArcGIS. They are slope data set, undulation data set, geological data set including landslide, collapse, debris flow, glacial lake, moraine, sand slope, spring point, dangerous rock, rock pile, earthquake fault zone, stratum lithology, water system and other elements, and humanistic data set including national highway and village.

Establishment of slope and undulation data set: In the previous surface analysis process, slope and undulation analysis has been carried out. On this basis, the slope and undulation factors are divided into 9 grades by reclassification analysis, and the grades increase with the increase of slope and undulation. The obtained terrain data set is shown in the following figure.

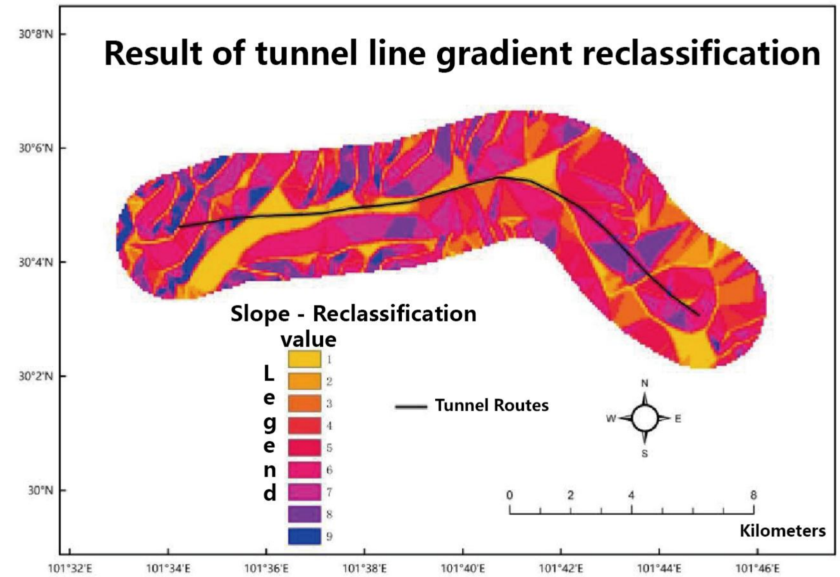

Figure 7. Result of tunnel line gradient reclassification.

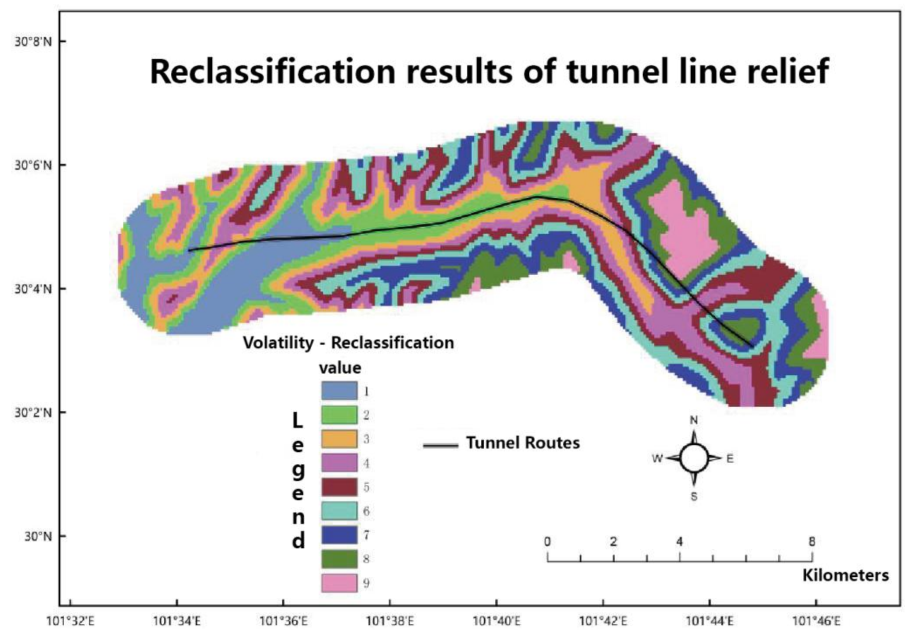

Figure 8. Result of tunnel line undulation reclassification.

Establishment of geological data set: The geological data set is mainly the geological influencing factors that affect the direction of tunnel route, including landslide, collapse, debris flow, moraine, sand slide slope, spring point, dangerous rock, rock pile, seismic fault zone, water system and other elements, and some elements are vector elements. According to the modeling requirements, all influencing factors are converted into grid elements after buffer analysis. Finally, the data of geological data set is reclassified and given cost value. The details are shown in the following figure.

Table 3. Geological data assignment table

Category	Landslide	Collapse	Debris flow	Moraine	Sand slide slope
Assignment	20	20	20	10	8
Category	Spring point	Dangerous rock	Rock pile	Seismic fault zone	Water system
Assignment	10	8	15	15	15

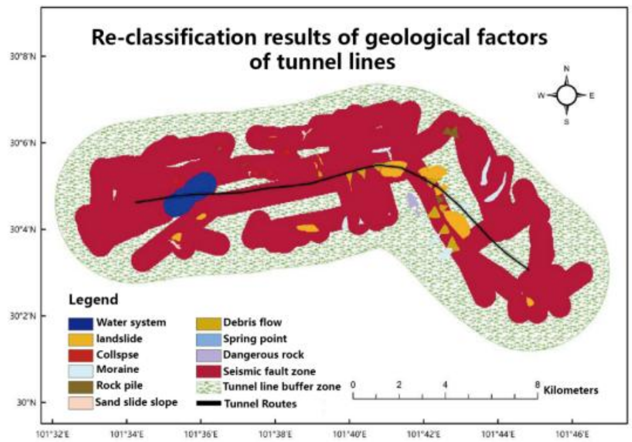

Figure 9. Display results of geological data set of tunnel route.

Establishment of humanistic data set: Comprehensive evaluation of the specific situation around the tunnel line, the humanistic data set here mainly includes national roads and villages. After the same method as geological data set processing, the human geographic information data set is obtained here.

Table 4. Geological data assignment table.

Category	National highway	Village
Assignment	15	8

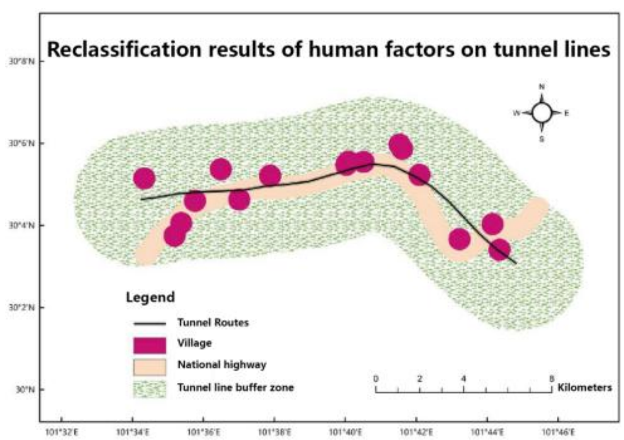

Figure 10. Display results of tunnel route human data set.

Establish a comprehensive model of tunnel route selection: Through the "reclassification" spatial analysis method in GIS software, the terrain, geology and human geography information data sets are obtained, and then the weight obtained by analytic hierarchy process is used to comprehensively analyze the five data sets, and finally the comprehensive route selection model is obtained. The results are shown in the following figure.

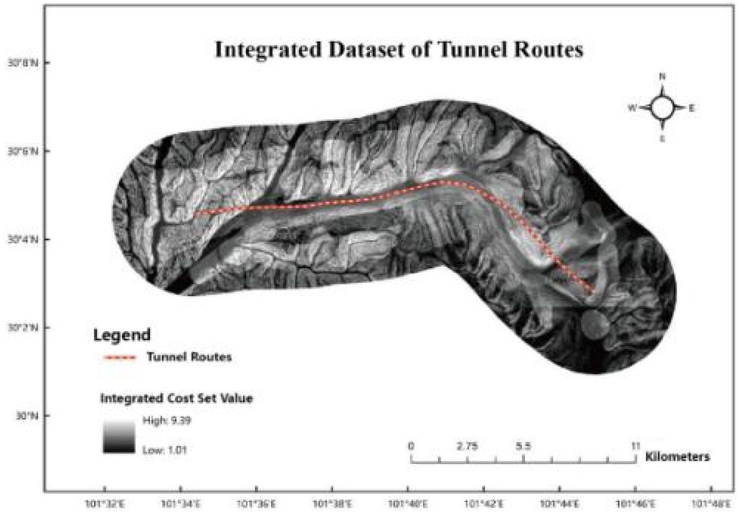

Figure 11. Tunnel route comprehensive data set.

4. RESULTS

Through the surface analysis of tunnel line and comprehensive data set analysis, it can be seen that the hydrogeological unit of the main construction parts of tunnel engineering is small, and the risk of outburst is small; Avoid bad geology; The highest undulation is 4446.97 m, and the lowest is 3446.66 m. Most of the tunnels are in low undulation areas. The highest slope can reach 103.08%, and the average natural slope is 36.02%. The condition is poor and belongs to the upper part of the mountain slope, but the tunnel line is located in a relatively low and gentle zone in this area; Most of the slope directions are north slope and northeast slope, which belongs to semi-shady slope. Compared with the (south slope) smooth slope, the temperature in this area is lower, the lower limit of permanent snow line is lower, precipitation is less, and the probability of disaster occurrence is low; It is close to the village and adjacent to National Highway 318, so the transportation is convenient, and the on-site passage is in good condition, which is convenient for roadway installation. To sum up, the design scheme of the tunnel is gentle in terrain, low in occasional disasters and convenient in transportation, which basically meets the design concept of tunnel route selection.

5. CONCLUDING REMARKS

Firstly, the surface analysis of the tunnel scheme to be evaluated is carried out, and the terrain information such as slope, aspect and undulation of the tunnel scheme is obtained. Then, the surface analysis results are combined with the geological and humanistic characteristics of the tunnel scheme, and four kinds of data sets of slope, undulation, geology and humanities of the tunnel scheme are obtained. After comprehensive spatial analysis, the comprehensive route selection model of the tunnel is obtained. Finally, the comprehensive tunnel analysis results are obtained by GIS comprehensive analysis method. This method has mature technology, easy operation and high feasibility, which provides a great reference for the evaluation of plateau tunnel scheme.

6. ACKNOWLEDGMENT

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