Establishment and Application of Ecological Suitability Evaluation System for Highway Route Selection of Subtropical Mountains

Establishment and Application of Ecological Suitability Evaluation System for Highway Route Selection of Subtropical Mountains

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Abstract. Subtropical mountains area Landsat8 satellite Tm images were used as information sources, RS technology was used to extract vegetation coverage, soil erosion and land use type for the evaluation of ecological background condition, and the GIS software was utilized to extract indices of terrain slope and water environment. Based on the indicators above, with GIS analysis techniques, comprehensive evaluation and analysis of the ecological background the subtropical mountains area were conducted, subtropical mountains ecological background conditions could be classified as excellent, good, fair, poor and very poor level. Based on the overall distribution and evaluation route corridors with relatively some feasible routes, and possible route options were compared to ultimately determine the best route with environmental coordination. The results show that the method overcomes the limitations of traditional line selection method which is too dependent on designers experience and subjective judgement.

1. Introduction

Highway traffic construction has promoted the rapid development of national economy. At the same time, construction and operation of the road process have caused various kinds of damage and pollution such as vegetation, land, natural landscape, air environment, water resources, etc. At present, with the development of the highway construction, the ecological impact of highway has got more attention. There have been many researches on the environmental impact of highway construction. The existing research on the impact of highway on ecosystem is mainly focused on the ecological negative effect of highway construction, such as influence of habitat, ecological disturbance and animal activity. The research on the suitability of different ecological systems for highway construction is seldom seen from the ecological system itself. The environmental impact assessment of engineering construction has been fully carried out. But it is the existing research on the influence of highway on ecosystem.

Subtropical mountains area, is widely distributed in China. Guangdong is a famous mountains area in China. In the process of highway route selection, it is a difficult problem for designers to minimize the impact of highway construction on the environment. In terms of ecological highway construction research, China is relatively backward compared with other regions in the world, there was still a large gap between the design concept and the design method, and the highway ecological selection in mountains area was selected at home and abroad. This paper takes HuiZhou-QingYuan expressway as

the supporting project, using RS and GIS analysis technology to carry out ecological route selection. The analysis and evaluation of the bottom environment, based on the overall distribution and evaluation results, find the route corridor with relatively small impact on the ecological environment, the final determination and environmental coordination is the best route, In order to protect the ecological environment in mountains area, the project will be brought into full benefit.

2. Materials and Methods

2.1. Description of study area

This study takes HuiZhou-QingYuan expressway as research area. HuiZhou-QingYuan expressway is an important part of the "two horizontal" road network in Guang Dong province. The route is 125.277 km, and the overall line shows the direction of things.

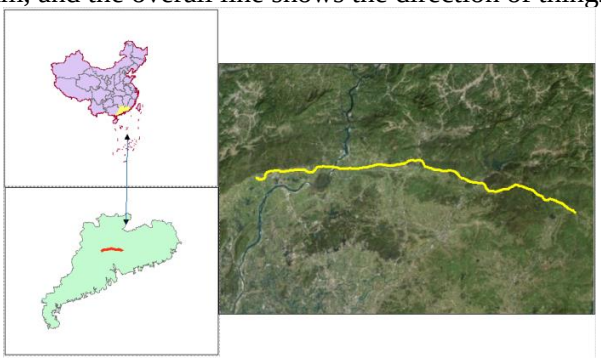

Figure 1. Location of study area.

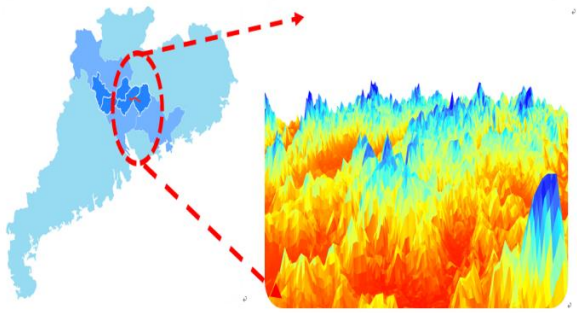

Figure 2. DEM of study area.

As statistics, up to 85% of the entire route is across or adjacent to the ecologically sensitive area, including the south Kun mountain national forest park, Tai he cave forest park and Liuxi River.

The study area's average elevation is 132~1825m and average annual precipitation is 2104.5～2284.8mm and focus on April to September .This study takes entire road as in boundary (E: 103°39'~104°02', N: 23°32'~23°49'), the area is about 859km^2.

2.2. Data Analysis

2.2.1. NDVI

The integration of Remote Sensing technology and Geographic Information System technology for ecological background information processing can not only improve the efficiency of processing information data, but also can reflect the ecological background of mountains area in objective reality and science effectively.

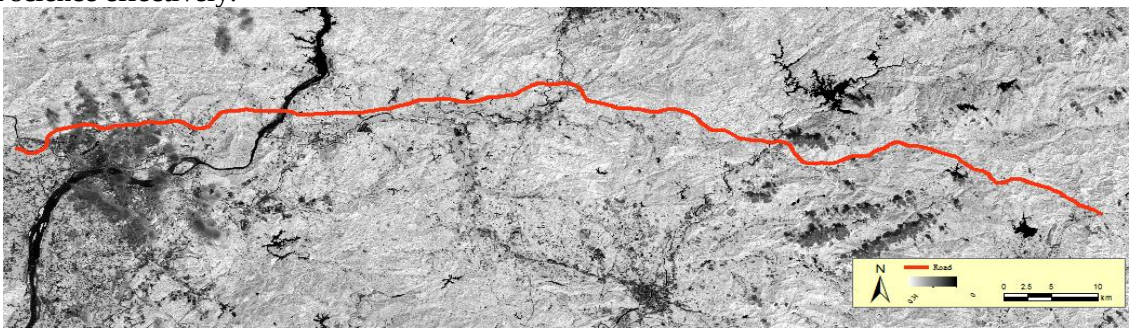

Figure 3. NDVI of study area

The information extraction and index classification NDVI (vegetation cover index) of vegetation cover index can effectively reflect plant growth state and vegetation spatial distribution density. The higher the value of NDVI, the higher the vegetation coverage in the region, the better the corresponding ecological background. The higher the vegetation index means the greener of the image.

According to the NDVI index chart, the land utilization rate is high, the original vegetation is destroyed seriously, and the cultivated vegetation is mainly cultivated, and the central part is dominated by shrubs.

Table 1. Vegetation index classification

Grade	Vegetation cover	NDVI	Number
5	Very excellent	＞0.6	9
4	Excellent	0.5~0.6	7
3	Good	0.5~0.6	5
2	Poor	0.5~0.6	3
1	Very Poor	＜0.2	1

According to the field survey results, NDVI is less than 0. The area of 2 is less vegetation, and NDVI is greater than 0. The area of 2 is the area with more vegetation distribution, and the index table of vegetation index is established.

2.2.2. Soil erosion

Soil erosion index has a mild erosion weight of0.05, moderate erosion weight is 0.25, and the heavy erosion weight is 0.7.

Table 2. Soil degradation classification

Grade	Degradation grade	Index	Number
5	Very excellent	80~100	9
4	Excellent	60~80	7
3	Good	40~60	5
2	Poor	20~40	3
1	Very Poor	0~20	1

2.2.3. Land use

Through remote sensing supervised classification was carried out on the processed image, get the original vector data classification, the application of RS and GIS data integration, incorporating hierarchical vector data for land use type vector data, and convert vector data to raster data, the types of land use information data, extract the information from land use types, the research of regional land use status is given priority to with forest land, cultivated land, followed by land, garden land and land for roads, residential land and waters less proportion.

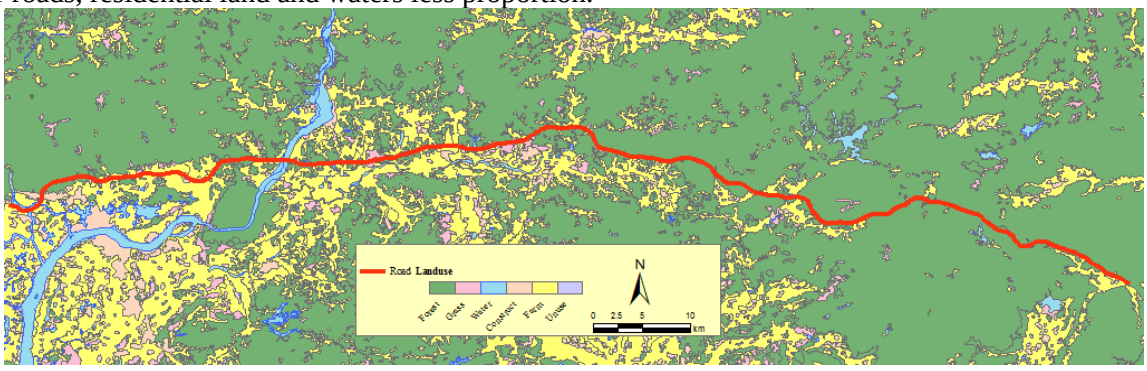

Figure4. land use of study area

The land resources along the route are very precious, so special attention should be paid to the protection of the land in the route selection, avoiding the densely populated residential areas as far as possible, and reducing the demolition buildings and soil erosion. According to human activities, the stronger the disturbance of ecological environment, the worse the ecological background environment, the higher the score, the smaller the human disturbance.

Table 3. Land use type score in study area

Land use	Vegetation	Watershed	unused land	Farmland	Construction land
Score	9	7	5	3	1

2.2.4. Terrain

The terrain slope index is based on the elevation point in the study area, and the GIS technology is applied to carry out data processing.

By generating TIN model and elevation map, the terrain slope information is finally extracted.

Table 4. Terrain slope classification

Grade	**Terrain slope grade**	**Terrain slope index**	**Number**
1	Very excellent	≤3°	9
2	Excellent	3°~6°	7
3	Good	6°~10°	5
4	Poor	10°~20°	3
5	Very Poor	＞20°	1

2.2.5. Water

Liuxi River, located in the northwest of Guangzhou, China, is a collection of streams. Originated in Conghua district LvTian Town meets the new venture, has collected many tributaries, through Huang Yao gorge (also known as stone horse gorge) into the flow river reservoir, beginning said flow river, also known As Lv Tian River. From the north to the south through the Conghua district, and then through the white cloud area of the clock, bamboo, people, Jiangcun and other places, into the Baini river, via the pearl river delta river network into the south China sea. From the source to the Baini estuary, the total length of the dry flow is 156 kilometres, and the drainage area is 2300 square kilometres.

Table 5. Water environment evaluation standard classification

Grade	**Flood discharging**	**Drainage standard**	**Soil erosion ($t.km^{-2}.a^{-1}$)**	**Number**
1	50 year return period	＞ 30 year	≤2500	9
2	30~50 year	20~30 year	2500~5000	7
3	20~30 year	10~20 year	5000~8000	5
4	10~20 year	5~10 year	8000~15000	3
5	＜10 year	＜5 year	＞15000	1

2.3. Approach

2.3.1. Ecological suitability

Ecological suitability is derived from the concept of land ecological suitability assessment, refers to the nature by a land use type is determined by its degree of the restriction of the appropriate for a particular purpose or by the land with the hydrology, geography, topography, geology, biology, humanities characteristics are determined. Land ecological suitability study from the characteristics of the structure and function of ecosystem types, by studying the adaptive mechanism, eventually determine different ecosystem types of suitability for different ways of land use, its subject is the ecological characteristics of land, the object is to use. Route selection of ecological suitability can be regarded as ecological system for highway construction suitability for this particular ways of land use, thus it can be regarded as a kind of land suitability analysis, the main body is the characteristic of ecological system object is the highway construction, road line selection of ecological suitability analysis is to determine for highway construction process of the land ecological features. Simply put, the ecological suitability of highway route selection is the proper degree of ecological system for highway construction.

The purpose of land ecological suitability analysis is scientific and reasonable analysis of the characteristics of the land, starting from the characteristics of land ecological system, according to its inherent suitability to carry on the reasonable planning of land use, the construction of human activities on the natural environment as small as possible negative impact, improve the ecological benefits. Counterpart, the route selection of ecological suitability analysis aims to analyse its ecological characteristics and ecological evaluation system for highway construction suitability, according to the ecological system internal suitability for route selection, make the highway construction on the ecological system as small as possible impact, to provide a scientific and reasonable basis for highway route planning, ultimately achieve the goal of the coordinated development of highway construction and ecological protection.

According to the concept and purpose of ecological suitability analysis of highway route selection, the suitability of ecological system for highway construction is analysed, the purpose of which is to select the route according to the inherent suitability of the ecosystem. Starting from the concept and purpose, route selection of ecological suitability analysis contains at least two layers of meaning: one is the regional ecosystem characteristics meet the basic requirements of highway construction, that is, from the perspective of the highway engineering construction, regional conditions suitable for the engineering construction needs, Second, the regional ecological system of highway interference has certain stability and resilience, that is, from the perspective of ecological protection, regional ecological system in engineering construction better stability and resilience.

2.3.2. Evaluation Index

Based on the connotation of ecological suitability of route selection, the ecological suitability evaluation of road selection includes two parts: one is the suitability evaluation of highway land, and the other is the sensitivity evaluation of ecosystem. Therefore, the evaluation index system should start from these two aspects, and the suitability of highway route selection should be determined through the comprehensive evaluation and analysis of two aspects. According to the requirements of highway construction on the ecological system, the land suitability evaluation from the natural conditions, land use, road connectivity three criteria, build the evaluation index system of ecological highway land suitable. According to the characteristics of the ecological system from the ecosystem services value, the vulnerability of the ecosystem, climate sensitivity, topography, hydrology, soil sensitivity six criteria, build the evaluation index system of ecosystem sensitivity.

Table 6. Evaluation index system of ecological sensitivity

Target Layer	**Rule Layer**	**Index Layer**
Ecological sensitivity index	Ecosystem services	NDVI Index
		Habitat
	Ecosystem vulnerability	Vegetation
		Nature reserve
	Climate	Rainfall
		Aridity risk
		Rainstorm risk
	Soil sensitivity	Soil fertility
		Thickness of the soil
	Hydrological sensitivity	Rivers, lakes, wetland
		Water reserve
	Topography	Elevation
		Slope
		Aspect

2.3.3. Ecological suitability evaluation method

Using the analytic hierarchy process (AHP), according to the ecological, environmental protection, resource development, regional planning, social and economic aspects of experts, pass the various elements down into the evaluation system of class time, through constructing judgment matrix, calculate and compare two judgments, the weight of each factor, the consistency check of judgment matrix CR value < 0.1 that the consistency of judgment matrix is acceptable. The types of indicators in the evaluation system are complex, and the dimensionality is different, and there is a lack of comparability. Therefore, it is necessary to standardize all the factors in the evaluation. In this study, normalization of evaluation indexes was standardized.

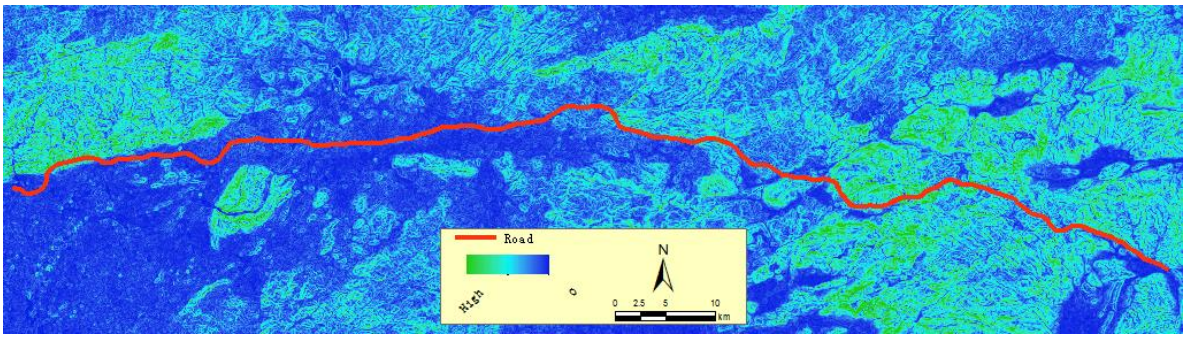

Figure 5. Result of study area

First according to the status of each index value and evaluation standard to determine the indexes of normalized values, then using the hierarchical merging step by step weighted summation respectively to calculate the highway land ecological suitability and ecosystem sensitivity, specific calculation formula is as follows:

$$P = \sum_{i=1}^{n} w_i \sum_{j=1}^{m} H_{ij}$$

P is the index of suitability index or ecosystem sensitivity of highway land, W_i is the weight of the ith criterion laye, S_{ij} is the weight of the JTH index in the ith criterion layer, H_{ij} is the standardized value of the JTH index in the ith criterion layer.

According to the highway land ecological suitability and ecosystem sensitivity calculation results, the overlay analysis, according to the principle of ecological priority, as shown in table 3 discriminant matrix recognition route the suitability of the results.

Table 7. Ecological suitability judgment matrix for highway selection

	Very inappropriate	**Not suitable**	**General**	**Suitable**	**Very suitable**
Very Low	3	3	4	5	5
Low	2	3	3	4	5
Middle	2	2	3	3	4
High	1	2	2	3	3
Very High	1	1	1	1	1

Note: 1 represents it's very inappropriate, 2 represent not suitable, 3 represent general, 4 represent suitable, 5 represent very suitable.

3. RESULTS AND CONCLUSIONS

(1) Analysing the vulnerability of mountains area ecological factors and the influence of highway construction on the ecological environment, vegetation, water environment, the terrain slope, soil erosion and land use types in mountain region ecological background investigation content and evaluation index.

(2) The acquisition and processing in October 2016, Landsat8 satellite TM remote sensing image, with the RS technology and GIS technology platform, access to the mountain area vegetation index,

soil erosion index, index of land use type, the water environment and terrain slope information of indicators, and analyses the various indicators and evaluation.

(3) Based on the expert scoring method, analytic hierarchy process and gray level correlation theory, the method of weight calculation of ecological background evaluation index was put forward, and the index weight was determined. Based on GIS technology, the five thematic maps are superimposed and analysed, and the ecological background status is evaluated comprehensively.

(4) Identify the ecological environment sensitive areas and non-sensitive areas in the study area, and find the route corridors with relatively small environmental impacts; using the road CAD software to design the feasible route plan, the feasible route plan is selected, and finally the route with the best coordination of ecological environment is determined.

Route selection of ecological suitability evaluation is from land ecological suitability evaluation yan stretch, road line selection of ecological suitability can be regarded as ecological system for highway construction suitability for this particular ways of land use. Route selection suitable ecological analysis characteristics from a regional ecological system, judge the degree of various factors for highway construction in the area of, also from the perspective of ecological protection at the same time, whether regional ecological system of engineering construction of good stability and recovery ability, so the route selection of ecological suitability analysis can provide scientific basis for highway planning line selection, to improve the decision-making level of highway planning and construction management has very important significance.

Acknowledgements

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References

[1] Shine R， Lemaster M， Wall M， et a1． Why Did the Snake Cross the Roads? Effects of Roads on Movement and Location of Mates by Garter Snakes (Thamnophis Sirta-lis Parietalis)[J]. Ecology and Society, 2004, 9(1): 9.

[2] Eaglin G S，Hubert W A． Management Briefs: Effects of Logging Roads on Substrate and Trout in Streams of the Medicine Bow National Forest, Wyoming [J]. North American Journal of Fisheries Management, 1993, (13):844-846.

[3] ZENG Xiaoyan, Xu Shunguo, Mu Rui-fang. Research on Karst ecological fragility [J]. Journal of Geological hazards and environmental preservation, 2006, 17(1)6-8.

[4] Schotten K, Goetgeluk R, Hilerink M, et al., Residental construction, Land use and the environment, simulations for the Netherlands using a GIS-based land use model[J]. Environmental Modeling and Assessments, 2001(6):133-143.

[5] Xiong Ying, Zeng Guang-ming, Lu Hui-hong, et al., Synthetic assessment of the eco-environment of Hunan province based on multi-source spatial information[J]. Journal of Hunan university national science, 2007, 34(10):87-90.

[6] GAO Zhiqiang, Liu Ji-yuan, ZHUANG Da-fang. The relations analysis between ecological environmental quality of Chinese land resources and Population [J]. Journal of remote sensing, 1999, 3(1):66-70.

[7] Minghao Mo, Jianhua MAO, Shurong Liang. Typical wetland cover change and protection of ecological environment in Poyang Lake based on RS and GIS technologies [J]. Journal of Earth sciences and environment, 2007, 29(2):210-213.