Environmental Engineering and Management Journal July 2020, Vol. 19, No. 7, 1157-1166
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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EVALUATION OF HIGHWAY CONSTRUCTION IMPACT ON ECOLOGICAL ENVIRONMENT OF QINGHAI-TIBET PLATEAU

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Abstract

This study is designed in order to determine the impact of Zhadao highway construction on ecological environment of Qinghai-Tibet Plateau, by comparing the quality of ecological environment before and after highway implementation. An index system of ecological environment impact evaluation of highway area is established, including terrain slope, vegetation coverage, desertification index and land use type. With the help of data mining and grey correlation degree theory, an ecological environment comprehensive evaluation model of multi index is proposed. This study analyzes the scale score of each evaluation index, and establishes a quantitative ecological environment evaluation model for highway areas in the Qinghai-Tibet Plateau. Taking Zhadao Highway in study area as an example, the state before and during the construction of the highway in 2014 and 2017 is selected for comparing and analyzing. The results show that the ecological environment in study area is obviously affected by highway construction. Significantly changed sections are concentrated in construction areas and urban residents densely populated area along the highway. Affected by factors such as highway earthwork and human activities, soil erosion has intensified, vegetation coverage has decreased, desertification has become more severe, and the overall quality of the ecological environment changed from superior to inferior.

Key words: ecological environment, impact evaluation, highway construction, grey relational grade, data mining, Qinghai-Tibet Plateau

Received: July, 2019; Revised final: January, 2020; Accepted: February, 2020; Published in final edited form: July, 2020

1. Introduction

As a large artificial civil structure, highway construction will bring some adverse effects on the ecological environment along highway, such as soil erosion, vegetation coverage declines, drastic desertification and ecological degradation etc. (Ma and Wang, 2006). With continuous construction and development of highways, the ecological impact on surrounding areas has been taken seriously (Sanchez et al., 2014; Wang et al., 2016; Qin et al., 2013; Qin and Zhou, 2012; Zhao et al., 2012). Gong et al. investigated the impacts of highway construction on the ecological environment based on ecological footprint analysis method (Gong, 2012). However, the current research is mainly for general areas, Qinghai-Tibet Plateau as a special area of ecological environment, and an ecological environment evaluation model needs to be established to mitigate the environmental impact caused by highway construction.

Some scholars have explored the rules of environmental quality changes before and after highway construction, and studied the key points and characteristics of the impact of highway construction on the surrounding ecological environment. Jia et al. discussed the impact of highway construction on vegetation coverage in high altitude areas (Jia et al., 2019). Vijay et al. collected and analyzed satellite images of Indian National Road No. 7 for 22 years.

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The analysis found that highway construction will lead to a reduction in the area of water bodies, changes in land use and land cover, and then lead to siltation and recharge (Vijay et al., 2017). Gallardo et al. studied two cases of environmental impact evaluation of highway construction to prove that human factors should be paid attention to, and the environment can be improved by changing working methods if necessary (Gallardo et al., 2016). The development of ecological environment evaluation methodology has encouraged increasing number of scholars to pay attention to the ecological environment evaluation of highway area. In 1971, geographic information system (GIS) technology has been applied in the evaluation of highway ecological environment in the United States (Li et al., 2017; Niu et al., 2010; Rahman et al., 2014; Xu et al., 2013). On the Microsoft.NET platform, Wu et al. (2011). designed and developed an ecological environment evaluation system along the roadsides of highway in mountainous areas based on GIS, Huang and Shen, (2011) constructed a framework of environmental impact evaluation system for highway construction using tools of remote sensing (RS) and GIS. Wang et al. considered the "post-earthquake effect" in the south-west area of China, and used the comprehensive evaluation results of ecological geological environment carrying capacity along the highway obtained by ArcGIS software to study the trend of geological ecological environment changes in a mountain region (Wang et al., 2016). Yao et al. analyzed Quick Bird image before and after construction period based on RS and GIS, and dynamically detected the impacts on ecological environment before and after highway construction (Yao et al., 2012).

Overall, in the current research, the structural framework of the environmental impact evaluation information system and highway ecological environment quality monitoring system combined with GIS technology have been initially established, but the existing evaluation system has a variety of indicators, standards are not uniform, and the applicability of quantitative models is insufficient. In addition, there are relatively few related studies on Qinghai-Tibet Plateau, a special ecological environment area with sensitive and fragile ecological environment and poor self-recovery ability.

Therefore, in view of negative ecological environment impact caused by highway construction on Qinghai-Tibet Plateau, this research takes the ecological environment of the highway area as the research object, and selects Qinghai-Tibet Plateau area in Qinghai, China as the research area to identify the ecological environment evaluation indexes of highway area. With the help of GIS technology platform, the grey relation degree theory is introduced to establish a quantified ecological environment evaluation model for highway area on Qinghai-Tibet Plateau. Taking the Zhadao Highway located in study area as an example, changes in the ecological environment of the highway area in 2014 and 2017 are analyzed. Through an accurate evaluation of the ecological environment of the highway area, the study dynamically grasped the process of ecological environment change before and after construction, which can provide a scientific basis for the ecological environment protection of highway area and sustainable development of highway construction on Qinghai-Tibet Plateau.

2. Material and methods

2.1. Study area and data

2.1.1. Study area

The study area is located in north of Qinghai-Tibet Plateau (100°57′2″-101°26′56″E, 36°23′24″-36°41′32″N). It lies in the transition zone from subtropical zone to warm temperate zone with obvious vertical climate differences, forming a special climatic zone superposed by subtropical zone, temperate zone and frigid zone. The average temperature in January is -14°C while in July is 18.3°C, and the maximum temperature can reach 34°C. Regional average annual precipitation is generally between 300-400 millimeters, hail and drought frequently occur. The study area is high in altitude, ranging from 2620 meters to 3760 meters, with a relative height difference is above 400 meters, the highest altitude is 4166 meters, and the relative height difference from the valley bottom is about 1100 meters. In this study area, the forest resources are less and unevenly distributed, the carrying capacity of the ecosystems is low and the response to environmental changes is relatively sensitive, so that the ecosystems are prone to take place degradation succession due to external disturbance. In that, ecosystems have weak self-healing capabilities and longer natural recovery times.

Zhadao Highway route starting point (K31 + 700) is located in Zhamalong Village, Duoba Town, Xining City, ending point (K103 + 074.652) is located in Daotanghe Town, Gonghe County. The overall direction of the route is from northeast to southwest, with an length of 65.207km, of which the mileage of the eight-lane section widened along the old road is 13.47km, and the mileage of the newly constructed four-lane section is 51.737km. Considering the geomorphological characteristics of study area, the landscape features along the route and the differences of plants site conditions in study area, the ecology along the highway was divided into the rivers-valleys (starting point ~ Moduoji K72 + 100) and the alpine meadow (Moduoji K72 + 100 ~ ending point). Zhadao highway expansion project began in April 2016, so far still in the main subgrade construction stage.

2.1.2. Data sources and processes

Data in study area mainly include DEM (Digital Elevation Model) terrain data and remote sensing image data. The DEM terrain data use the ASTER GDEM V2 data at 30 meters resolution, and the remote sensing data use the Landsat-8 satellite data. In this study, ENVI software was used to pre-process the initial data in study area, such as radiation correction and image fusion. After that, basic data for the summer of 2014 (before highway construction) and 2017 (during highway construction) were obtained (Fig. 1).

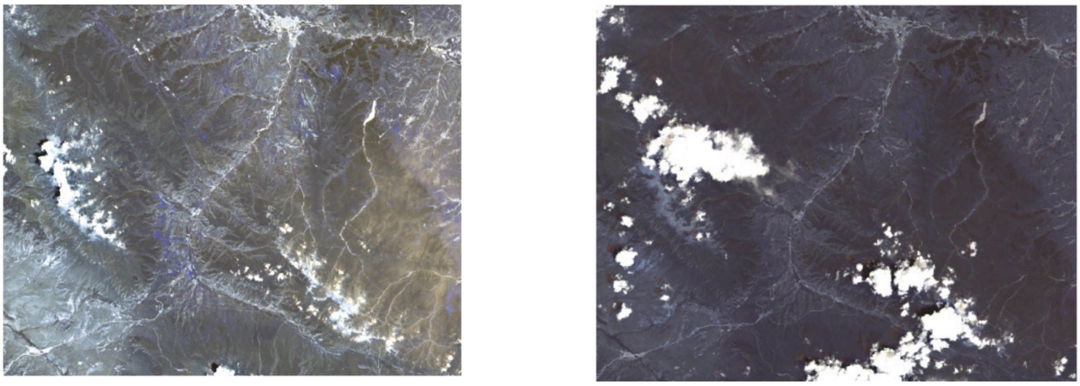
Taking the area of 300 meters on both sides of the route as the scope of the ecological environment evaluation of highway area, the buffer data of highway area was extracted to remove parts outside the study area. Regional vector polygonal can be obtained by spatial buffer analysis of the highway centerline data using ArcGIS, where the buffer radius is 300 meters, and then the image data of study area is obtained through the image clipping operation of ENVI, as shown in Fig. 2.

2.2. Theory and method

2.2.1. Selection of ecological environment evaluation index

Highway ecological environment evaluation involves related theories and methods in a variety of disciplines, such as systems science, ecology, and highway engineering. The evaluation index system should be systematic, comprehensive, dynamic and practical. At present, the Pressure-State-Response (P-S-R) frame model is the most widely used index model in the design of index systems internationally (Ke et al., 2015; Lee et al., 2016; Liu et al., 2016; Lu et al., 2016).

This framed model is more in line with the basic idea of ecological environment evaluation index system of highway area. First of all, human activities, such as highway construction, exert pressure on the highway ecosystems and cause some impact and destruction. Then, highway ecosystem has changed their state due to pressure, such as soil erosion, vegetation coverage declines, drastic desertification and ecological degradation etc. Finally, relevant highway management departments take corresponding measures to adjust the state of highway ecosystems to balance and health. P-S-R frame model expresses the relationship between human activities and the ecological environment through a certain logical relationship. Therefore, selecting the P-S-R frame model as the basic logical structure of the index system for ecological environment evaluation can meet the ultimate goal of ecological environment evaluation.



(a) 2014 (b) 2017

Fig. 1. Summer remote sensing image of the study area, (a) 2014; (b) 2017

Fig. 2. Cropped remote sensing image of highway area (2017)

The key to evaluating highway ecological environment is to evaluate its state truthfully. Through Literature review, interviewing relevant experts and analyzing the impacts of highway construction on the ecological environment, the state indexes that characterize the highway ecological environment quality were selected, which are terrain slope, vegetation coverage, desertification index and land use type. Taking Landsat-ETM data of study area as the information source, these evaluation indexes were extracted by using ENVI and ArcGIS, as shown in Figs. 3-6.

2.2.2. Weight of indexes

In this paper, four ecological environment evaluation indexes have different impacts on highway construction. In order to reflect its comprehensive impact on highway construction more realistically and accurately, each index needs to be given a weight. Index weights can express the impact or importance in the quantitative parameter system. Based on the grey relational grade theory, this study uses the grey relational grade of indexes to determine the weight of the ecological environment index of highway area.

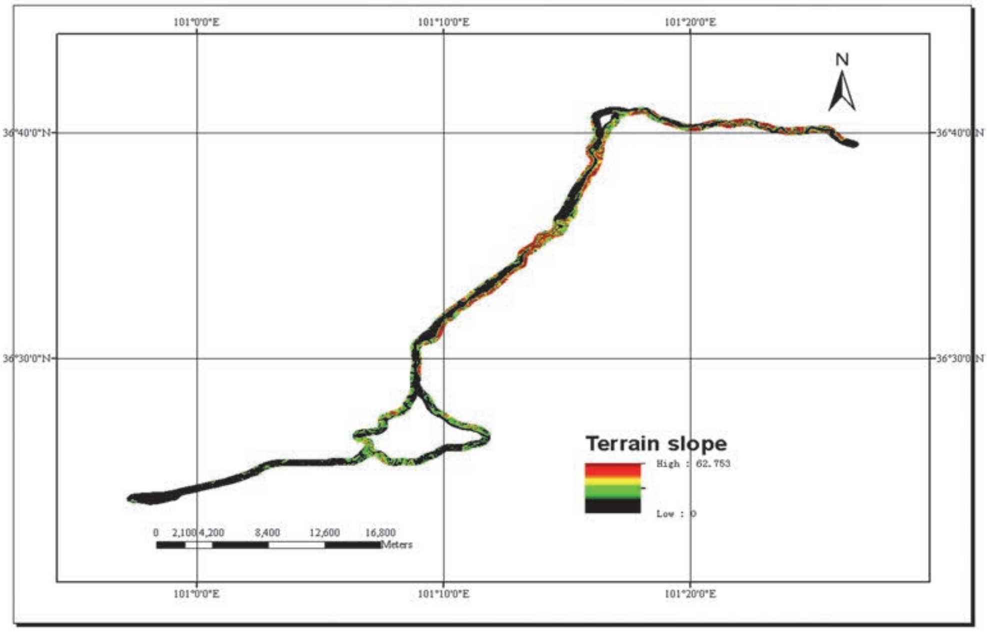


Fig. 3. Map of terrain slope

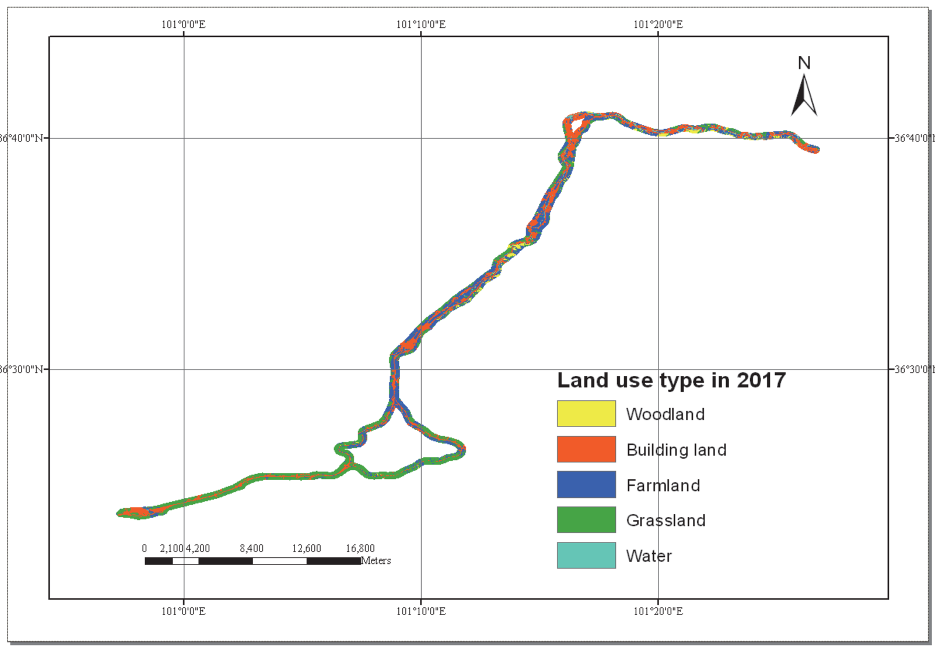


Fig. 4. Map of vegetation coverage in 2017

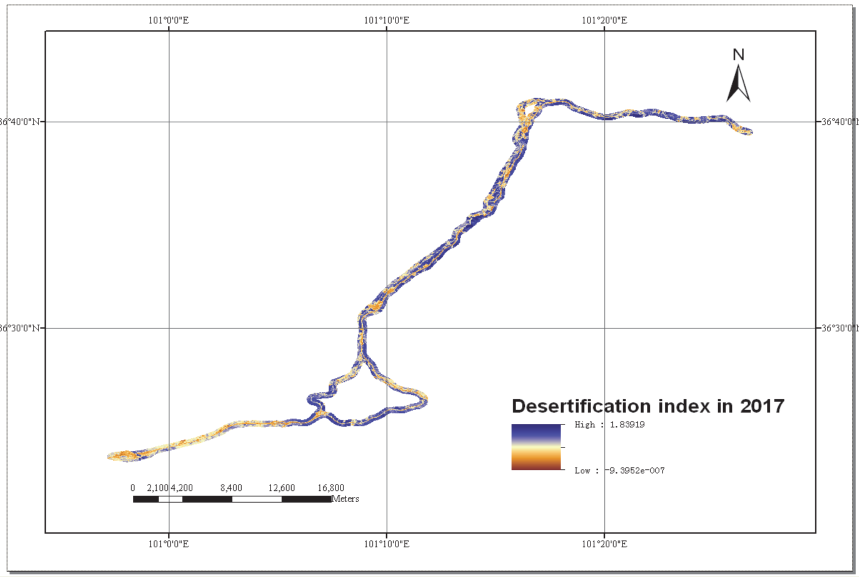


Fig. 5. Map of desertification index in 2017

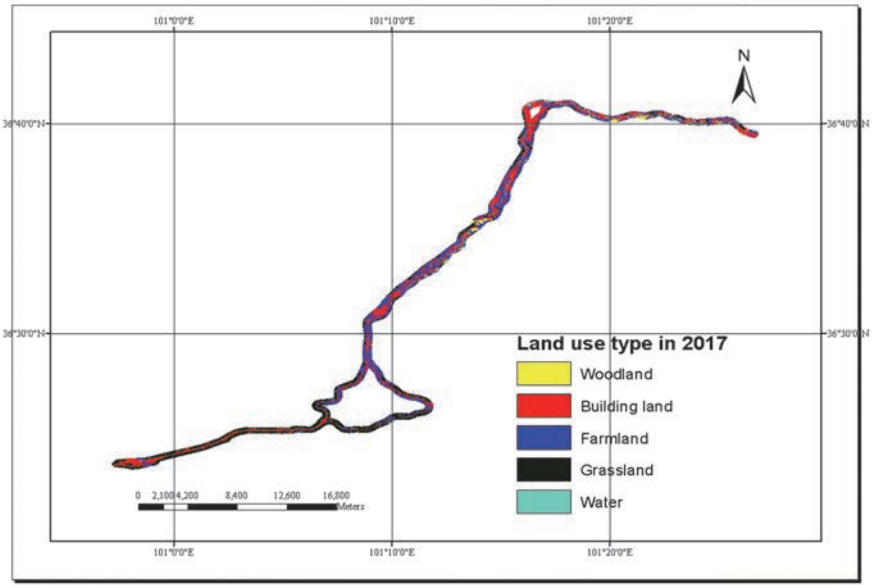


Fig. 6. Map of land use type in 2017

The specific process is as follows:

(1) Determining the parent index and sub index:

In this study, the main index affecting the ecological environment was selected as the parent index, namely the index with the largest vector sum value. Let the index value vector corresponding to the parent index be $Y_0 = (x_{10}, x_{20}, \cdots x_{n0})^T$, as the parent sequence. Other indexes were used as sub index, and the index value vector corresponding to the sub index was recorded as $Y_j = (x_{1j}, x_{2j}, \cdots, x_{nj})^T$ $(j = 1, 2, \cdots, m)$, which was the sub sequence.

(2) Averaging

Firstly, calculate the average number $\frac{1}{n}\sum_{i=1}^{n} x_{ij}$ of each original series separately. Then, use all the data x_{ij} of the series divided by the average number of the series to obtain a multiple number column x_{ij}' of each datum concerning its average number, which is the average matrix (Eq. 1):

$$x_{ij}' = x_{ij} \Big/ \frac{1}{n}\sum_{i=1}^{n} x_{ij} \tag{1}$$

(3) Initialization

In solving the averaging matrix, the first value in the same sequence is used to divide all the values in the same sequence, so obtain a multiple sequence of each value relative to the first value, which is the initialized sequence. (Eqs. 2-3). Process Y_0 and Y_j separately.

$$x_{i0}' = x_{i0} / x_{10} \tag{2}$$

$$x_{ij}{}' = x_{ij} \big/ x_{1j} \quad (3)$$

$Y_0{}' = (x_{10}{}', x_{20}{}', \cdots, x_{n0}{}')^T$, $Y_j{}' = (x_{1j}{}', x_{2j}{}', \cdots, x_{nj}{}')^T$.

From this, the initialization index value matrix is obtained: $B = (Y_0{}', Y_j{}')$.

(4) Calculating the relational coefficient and relational grade

The relationship coefficient between Y_0 and Y_j is calculated as (Eq. 4):

$$y_{ij} = \frac{\min\limits_{1\le j\le m}\min\limits_{1\le i\le n}\left|x_{i0}{}' - x_{ij}{}'\right| + \rho \max\limits_{1\le j\le m}\max\limits_{1\le i\le n}\left|x_{i0}{}' - x_{ij}{}'\right|}{\left|x_{i0}{}' - x_{ij}{}'\right| + \rho \max\limits_{1\le j\le m}\max\limits_{1\le i\le n}\left|x_{i0}{}' - x_{ij}{}'\right|} \quad (4)$$

Type: ρ for resolution coefficient, $\rho \in (0,1]$, usually takes 0.5

Obtain the relational coefficient matrix: $Y = (y_{ij})_{n\times m}$

Average the columns of the matrix (Eq. 5):

$$y_j = \frac{1}{n}\sum_{i=1}^{n} y_{ij},\ j = 1,2,\cdots,m \quad (5)$$

The formula reflects the relational grade between the jth index and the parent index. The greater the value of y_j is, the closer the jth index is to the parent index, and the greater the impacts on the ecological environment, so the proportion of this index in the entire index system is also greater.

(5) Determining the weight

Normalization process $y_i{}'$ ($j = 1,2,\cdots,m$), then (Eq. 6):

$$\omega_j = y_j \Big/ \sum_{j=1}^{m} y_i,\ j = 1,2,\cdots,m \quad (6)$$

$W = (\omega_1, \omega_2, \ldots, \omega_m)$ can be used as index weight.

2.2.3. Construction of the ecological environment evaluation model of highway area

Each evaluation index has different properties and different dimensions. In a comprehensive evaluation of ecological environment, they need to be scaled with e_i to establish a unified dimension, and e_i represents the scale value of each evaluation index in this study. By summarizing existing relevant research combined with expert consultation, evaluation indexes are divided into five levels: excellent, good, medium, bad and poor. Each level is separately assigned 9, 7, 5, 3, and 1. With reference to related research (Wang et al., 2019; Yan et al., 2018; Zhou et al., 2018), consider the characteristics of the fragile areas of the ecological environment on Qinghai-Tibet Plateau, modify the index classification, classification standards of each index are shown in Table 1. Through the above process, unified dimensional calculation and analysis of evaluation indexes can be performed.

After quantifying the each evaluation index and determining the weight of evaluation indexes, an ecological environment comprehensive evaluation model of multi index is established, as shown in the following equation (Eq. 7):

$$E = \sum_{i=1}^{n} \omega_i e_i \quad (7)$$

Type: E for comprehensive index of ecological environment, ω_i ($i=1,2,3,4$) for the weight of each index, e_i ($i=1,2,3,4$) for the scale value of each evaluation index. The larger the value of ecological environment comprehensive index, the better the corresponding ecological environment quality of highway area.

3. Results and discussion

3.1. Application of grey relational theory

Based on the grey relational theory, this study first used the Analytic Hierarchy Process (AHP) based on expert scoring. According to the established factor evaluation index system, then divided into different levels to form a hierarchical structure model of index evaluation. The model is mainly composed of three levels: the target layer, the criterion layer, and the index layer.

According to the hierarchical analysis structure model, the concrete process quantified according to a scale of 1-9. Thirty highway experts with senior professional titles and many years of practical experience were selected to score four indexes of terrain slope (r_1), vegetation coverage (r_2), desertification index (r_3) and land use type (r_4). Based on the scoring results, a series of comparative judgment matrices are formed. Then perform a random consistency ratio C.R. test, the weight value of each index given by each expert is obtained, and it is summarized in Table 2. Vegetation coverage has the largest total weight, which is 11.25274. Therefore, the vegetation coverage index was determined as the parent index while the other indexes were determined as sub indexes.

Table 1. Evaluation index system of ecological environment of Zhadao Highway area

Evaluation index	***Index rating and classification standards***				
	Excellent	***Good***	***Medium***	***Bad***	***Poor***
Value	9	7	5	3	1
Terrain slope (°)	≤2	2-6	6-15	15-25	>25
Vegetation coverage	≥0.6	0.45-0.6	0.3-0.45	0.1-0.3	<0.1
Desertification index	≤1.15	1.15-1.5	1.5-1.8	1.8-2	>2
Land use type	Woodland	Grassland	Water	Farmland	Building land

Table 2. Result of the weight value of each index

	r_1	r_2	r_3	r_4
1	0.42099	0.42099	0.11642	0.04162
2	0.41002	0.16002	0.32719	0.10276
3	0.09396	0.42728	0.15879	0.31997
4	0.13685	0.38685	0.35453	0.12177
5	0.43638	0.43638	0.04336	0.08387
6	0.14249	0.39249	0.30430	0.16072
7	0.09287	0.81287	0.06327	0.03100
8	0.39249	0.14249	0.16072	0.30430
9	0.29097	0.29097	0.31033	0.10774
10	0.44410	0.44410	0.04221	0.06959
11	0.16737	0.50070	0.20934	0.12259
12	0.58871	0.21371	0.06653	0.13105
13	0.27436	0.27436	0.31157	0.13971
14	0.09948	0.43281	0.15500	0.31271
15	0.14220	0.39220	0.32891	0.13669
16	0.07913	0.20413	0.51045	0.20630
17	0.13601	0.38601	0.35316	0.12482
18	0.27597	0.27597	0.29727	0.15079
19	0.12170	0.74670	0.08906	0.04255
20	0.57939	0.20439	0.08001	0.13621
21	0.10539	0.43872	0.34559	0.11030
22	0.42049	0.42049	0.12334	0.03568
23	0.42117	0.42117	0.11958	0.03808
24	0.26350	0.26350	0.35875	0.11425
25	0.26813	0.26813	0.28932	0.17442
26	0.14159	0.69714	0.12672	0.03455
27	0.22702	0.67702	0.07562	0.02033
28	0.26235	0.26235	0.16810	0.30719
29	0.38880	0.13880	0.34447	0.12793
30	0.45333	0.12000	0.29712	0.12955
Total	8.27721	11.25274	6.53103	3.93904

According to the formula (Eq. 1) ~ (Eq. 6), the basic data were processed to get the grey relational grade and weight, as shown in Table 3. Consequently, the comprehensive index of ecological environment is expressed as (Eq. 8):

$$E=\sum_{i=1}^{n}\omega_i e_i=0.27e_1+0.31e_2+0.23e_3+0.19e_4 \qquad (8)$$

3.2. Results and discussion

According to the above evaluation indexes and classification standards, the distribution of terrain gradient, vegetation coverage, desertification index and land use type of study area were obtained by ArcGIS technology platform. After the quantification of a each evaluation index, the comprehensive index of highway ecological environment on Qinghai-Tibet plateau area was calculated according to the weighted layer stacking principle and ecological environment comprehensive evaluation model of multi index. To reveal the difference of ecological environmental quality more clearly, the classification of the comprehensive ecological environmental index of Zhadao Highway area in Table 4. The ecological environmental index was divided into five levels, and the spatial distribution of the comprehensive index of ecological environment in 2014 and 2017 is shown in Fig. 7. Table 5 shows the statistical results of ecological environment comprehensive evaluation in study area. The results show that the ecological environment of study area is obviously affected by the highway construction, which is manifested in the following aspects:

(1) In 2014, the excellent-level areas, 7.71 km^2, were mainly distributed in two sections of K79 + 500 to K94 and K82 to K94, which belong to the Riyue Mountain ranges in the alpine meadow. In this area, low-lying hills and wide-and-low valleys appear alternately, and the terrain is less undulating. Grassland was the main land use type, with better vegetation coverage and less interference from human activities. In 2017, the area of the excellent-level areas were 6.34 km^2, and the proportion of excellent-level areas in study area dropped by 2.3% compared with that before construction. Excellent-level areas changing parts mainly distributed along the Zhadao Highway construction project area.

(2) Good-level areas, the largest proportion of the region, with an area of 27.78 km^2 in 2014, mainly located in the non-resident living areas from the starting point of highway to the section of Riyue

Mountain in the rivers-valleys. The land use type was mainly farmland, and some grassland and woodland. There are mainly eroded hills and valleys in the area, and steep slopes alternate with gentle slopes with little desertification impacts, but strongly influenced by human activities.

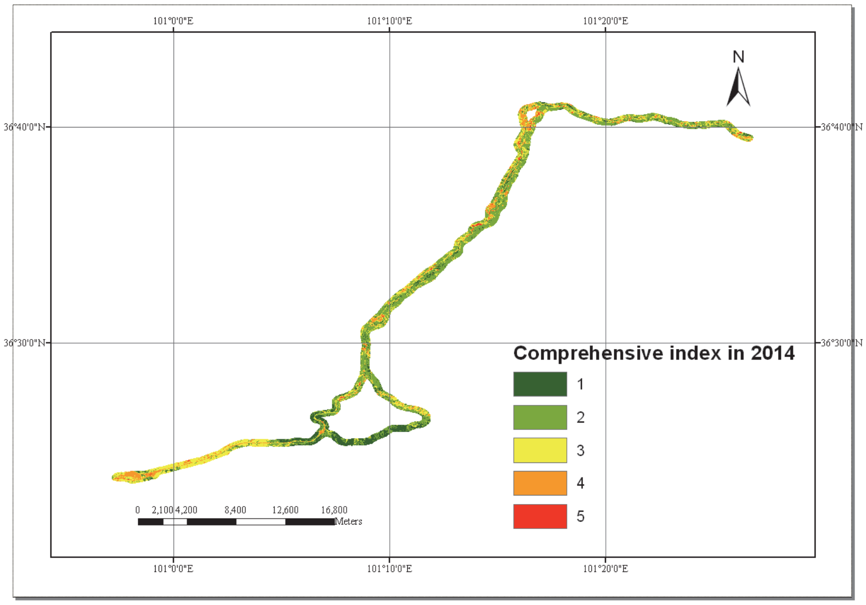
In 2017, the area of good-level in study area was 25.72 km^2, and its proportion decreased by 3.5% compared with the pre-construction level. It was mainly concentrated in the Zhadao Highway construction project area and abandoned and artificially filled sections.

Table 3. Grey relational grade and weight

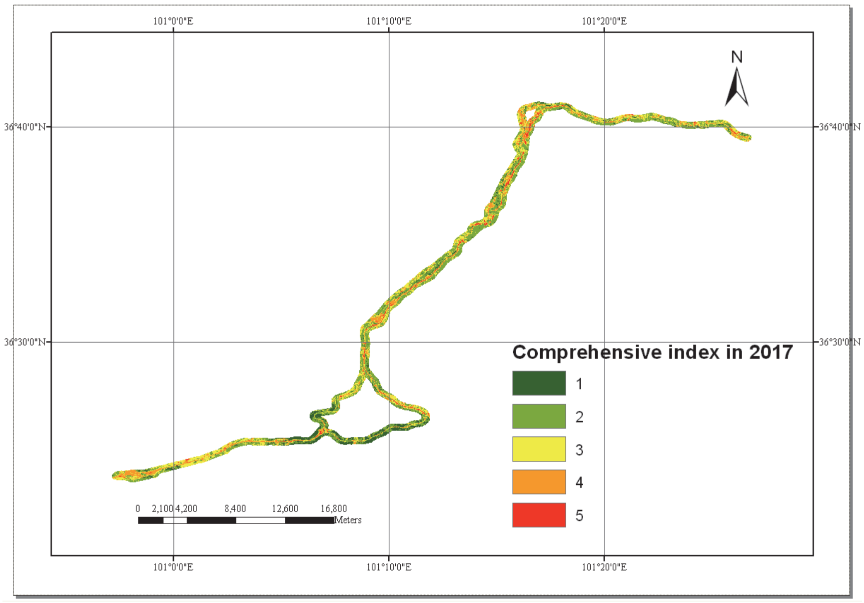
	y_0	y_1	y_2	y_3
Grey relational grade	1.00000	0.88113	0.75262	0.63290
Weight	0.31	0.27	0.23	0.19

Table 4. Ecological environment quality level of Zhadao Highway area

Level	***1***	***2***	***3***	***4***	***5***
Eco-environment quality	Excellent	Good	Medium	Bad	Poor
Eco-environment index	≥7.5	5.5-7.5	3.5-5.5	2.0-3.5	<2.0



(a)



(b)

Fig. 7. Classification map of the comprehensive index of eco-environment: (a) 2014; (b) 2017

Table 5. Statistical table for comprehensive ecological environment evaluation of highway area

	2014		*2017*	
	Area (km^2)	*Proportion of evaluation area (%)*	*Area (km^2)*	*Proportion of evaluation area (%)*
Excellent	7.71	13.0	6.34	10.7
Good	27.78	46.8	25.72	43.3
Medium	16.63	28.0	16.77	28.3
Bad	6.52	11.0	8.69	14.6
Poor	0.71	1.2	1.83	3.1
Total	59.35	100	59.35	100

(3) Middle areas of the region accounted for a larger proportion of evaluation, mainly in hilly plateau area from the Riyue Mountain Pass to the ending point of highway in the alpine meadow, no significant changes in the ecological environment around the highway construction.

(4) Bad-level areas in 2014 have an area of 6.52 km^2, accounting for a smaller proportion of the evaluation area. Scattered in engineering construction areas along the highway, Huangyuan interchange, Tuergan Village, Xiaogaoling Village and other buildings or urban residents densely populated area, which were strongly influenced by human activities. Vegetation coverage in the areas was relatively low, desertification has a greater impact. In 2017, the area of the bad-level areas was 8.69 km^2, which accounted for an increase of 3.6% compared with that before construction, mainly due to the new artificial construction area along the highway.

(5) In 2014, the area of the very poor level areas was 0.71 km^2, which accounted for a small proportion of the evaluation area and mainly due to desertification. Affected by the earthwork's construction and other factors, the area of the very poor level areas was 1.83 km^2 in 2017, accounting for an increase of 1.9%, and it was mainly distributed on the highway abandoned slag and artificial soil filling sections.

(6) According to the overall analysis, the ecological environment quality level in 2014 was higher than that in 2017. Before and after the construction of highway, the area of excellent and good level areas decreased by 5.8%, and the area of bad and very poor level areas increased by 5.5%. Highway construction significantly affects the ecological environment of study area, and the significant changes in study area were concentrated in the Zhadao Highway construction project area and abandoned and artificial filled sections. Highway construction affects the ecological environment in high altitude areas. Affected by factors such as earthwork construction and human activities, soil erosion has been aggravated, vegetation coverage has been reduced, desertification has become more serious, resulting in weakening of environmental conditions within the highway area, and the quality of ecological environment has become increasingly severe.

In addition, the greatest change of ecological environment index in the rivers-valleys was 6.26, while in the alpine meadow was 5.80. The quality of ecological environment changed from superior to inferior, and the change was significant.

4. Conclusions

In this study, indexes affecting the ecological environment of highway area on Qinghai-Tibet Plateau were systematically studied and an ecological environment evaluation model was established. Zhadao Highway in the Qinghai-Tibet Plateau was taken as an example for calculation and analysis. The results and conclusions are as follows:

(1) Considering the systematisms, comprehensiveness, dynamics and practicability of evaluation index system, terrain slope, vegetation coverage, desertification index and land use type were taken as ecological environment evaluation index. An ecological environment evaluation model for highway area based on grey correlation was established to characterize the ecological environment quality of highway areas.

(2) Single evaluation index and comprehensive evaluation index classification methods were established. According to the comprehensive index of ecological environment, ecological environment quality could be divided into 5 levels: excellent, good, medium, bad and poor, and the distribution of ecological environment condition in study area could be demonstrated more clearly.

(3) By applying the method of ecological environment evaluation of highway area based on grey correlation degree, this study realizes the quantitative evaluation of highway ecological environment in Qinghai-Tibet Plateau. Evaluation method provides a scientific basis for the dynamic control of ecological environment changes during highway construction in the Tibetan Plateau and the responses of measures put forward highway area environmental protection. It promotes the sustainable development of ecological environment protection and highway construction in highway areas of the Qinghai-Tibet Plateau.

Acknowledgements

This research was funded by Natural Science Basic Research Plan in Shaanxi Province of China, (Program No. 2017JQ5122 and No. 2018JQ4009) and the Science and Technology Project of Transportation Department of Qinghai Province (Program No. 2016-03).

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