



Assessment of ecological environment impact in highway construction activities with improved group AHP-FCE approach in China

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Received: 8 January 2020 / Accepted: 2 June 2020 / Published online: 24 June 2020
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Abstract Highway construction is time consuming and complicated. Various environmental issues can be encountered during this process. Therefore, it is necessary to assess the impact of ecologic environment in highway construction. However, the traditional assessment approaches paid more attention to the environmental factors rather than the ecological problems, and the weights of evaluation indexes were assigned with relatively average values, which cannot comprehensively and accurately to assess the impact of ecological environment in

highway construction. In order to solve these problems, this paper established a new model to combine improved group AHP and FCE. A total of six main factors and 22 sub-factors from three aspects of social, ecological, and natural environment were identified. The model and index system were applied to the ecological environment impact assessment of the highway from the city of Hanzhong to Lueyang County section in Shaanxi Province, and compared with traditional fuzzy AHP approach to verify the feasibility of this model. The results showed that only the ranking of social and ecological factor changed when comparing with the traditional approach. The weight of social factor determined by the improved approach was 0.2835, while that of the traditional approach was only 0.2365, and the weight difference was 0.047. This improved approach highlighted the importance of social factor and overcame the equal weight distribution of traditional approach, which made the overall weight ratio distribution more reasonable and objective. The comprehensive assessment result was 0.3482, which was in line with the “general impact” level. This was consistent with the actual situation of highway construction. The improved group AHP-FCE model could be used successfully for assessing the impact of the ecological environment in highway construction, and it had good applicability and popularization value in ecological environment assessment.

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Keywords Ecological environment impact assessment · Highway construction · Analytic hierarchy process

(AHP) · Improved group AHP approach · Fuzzy comprehensive evaluation approach (FCE)

Introduction

The highway has become an important part of the modern transportation system with its characteristics of speed, convenience, and wide coverage (Liu and Wang 2018), which indicates the level of social and economic development of a country or region to a certain extent. However, it not only brings great economic and social benefits but also some environmental problems such as soil erosion and biodiversity reduction (Nematollahi et al. 2017; Qian et al. 2001; Tu 2016). So how to realize the harmonious and sustainable development of the highway construction projects and the social and natural environment, it is particularly important to carry out the ecological environment impact assessment of the highway construction.

Environmental impact assessment is an important task of environmental protection, it is an effective means and approaches of implementing the strategy of sustainable development in decision-making and developing construction activities (Salvador et al. 2000). However, the traditional assessment approaches paid more attention to the environmental factors rather than the ecological problems, and the highway construction projects had more impact on the ecological environment security. Therefore, the ecological environment impact assessment was very necessary for highway construction projects. The ecological environment system of highway construction was a complex system and the rational selection of comprehensive quantization model was a key to scientific environmental assessment (Tu 2016). Different approaches to assessment have been suggested from classical simple approaches to fuzzy approaches (Aminbakhsh et al. 2013).

At present, the environmental impact assessment research approaches related to highways include traditional AHP, grey correlation analysis, and fuzzy comprehensive evaluation (FCE) approach (Qizhou and Hua-pu 2009; X. Zhang et al. 2012; Akay et al. 2018; Lyu et al. 2018; Lv and Ji 2019; Lin et al. 2019; Han et al. 2019). As stated in these studies, environmental impact assessment approaches and index system did not appear to have a sufficiently comprehensive framework. Jing focused only on the two major types of influence factors, natural and

social environment through road analysis of the construction period (Jing 2008). Two other studies (Z. Wang and Chen 2010) (X. Zhang et al. 2012) also assessed limited impact factors (5 impact factors), such as soil, water, plants, animals, and soil erosion. Huang et al. (Huang and Yeh 2008) pointed out that the index evaluation system of green highway needed to be further improved and social factors should be added. It can be seen that the evaluation system needs to be improved. Akay et al. (Akay et al. 2018) adopted fuzzy AHP to assess the six main risk factors and 22 sub-risk factors during the forest road design and construction process. The results demonstrated that the fuzzy AHP method can be used effectively to assess the risks of forest road design and construction. Singh et al. (Singh et al. 2017) dealt with assessment of air quality in Haora River basin using fuzzy comprehensive assessment (FCA) and AHP method. The results have clearly highlighted superiority and robustness of this method in determining air quality indices under study. It has effectively addressed the inherent uncertainties involved in the evaluation, modeling, and interpretation of sampling data. These literatures were all studied by fuzzy AHP approach. Although, classical AHP was one of the assessment approaches most commonly used by decision makers and researchers (Vaidya and Kumar 2006). It was used to solve complex multi-decision problems involving qualitative judgments (Saaty 1980). However, the use of unbalanced scale judgments and the inability to adequately provide ambiguity in the pairwise comparisons phase often caused the AHP to be criticized (Deng 1999). Traditional fuzzy AHP approach followed the principle that the weight of each expert was equal, regardless of the negative effects because of the differences in experts' knowledge background. In other words, the subjective judgment and selection preference of the expert had a great impact on the results (Gao and Li 2004) and the comprehensive results did not take into account the opinions of multidisciplinary experts and various stakeholders, making them unreliable and unconvincing.

Therefore, scholars have improved the approaches to overcome the shortcomings in determining the weight of the traditional fuzzy AHP approach. For example, Zhang et al. (Y. Zhang and Yang 2016) used the combination of group AHP

and entropy weight approach instead of AHP to determine the index weight, reducing the interference of human factors and improving the evaluation accuracy. Zhang et al. (X. Y. Zhang et al. 2020) adopted the combination of AHP and PCA to assess the safety of road construction system. The results demonstrated that judgment dispersion naturally existing in classical AHP can be effectively reduced when combined with PCA. In order to determine the location of the distribution center, Zhou (Zhou 2011) used the group AHP to determine the weight of each index, and then used the FCE for single-index and multi-level comprehensive assessment of the alternative address. This indicated that the group AHP-FCE approach was suitable for complex and variable system modeling methods, which combined qualitative and quantitative methods to make complex problems clear. However, the traditional group AHP approach treated all experts “equally,” that is, equal weighting, which failed to highlight the importance of some key indicators. In fact, it was limited by subjective factors. Because the expert individual ranking vector weight coefficients were often artificially determined based on factors such as the individual’s reputation and authority currently, it was very difficult to compare the reputation and authority of experts. On the other hand, scientifically quantifying comparison results was also complicated. According to the literature, most studies currently used equal weighted averaging to calculate group expert weights. Based on this, Xia (Xia et al. 2011) has explored the approach of determining the weight of experts, and proposed an improved group AHP approach, which was used to determine the weight of medical insurance business assessment. It not only respected the result of individual judgment and its accuracy, but also paid attention to the comprehensive opinions of the group. However, the combination of improved group AHP and FCE method has not been used in the assessment of the ecological environment of highway construction. It can be seen that the advantages of the improved group AHP method in determining the weight of experts were fully exploited, and the complementary advantages of assessment methods were valued, which was of positive significance for the assessment of complex systems.

Considering the lack of comprehensiveness of the environmental impact assessment of highway

construction, this paper established a comprehensive index system based on social, ecological, and natural factors. It attempted to build an improved group AHP-FCE approach to assess the environmental impact of the construction of the highway from the city of Hanzhong to Lueyang County section in Shaanxi Province. Compared with the traditional approach, the superiority and accuracy of the improved approach were verified.

Methodology

Figure 1 lists various steps of methodology used to evaluate the impact of highway construction on the ecological environment located in the city of Hanzhong to Lueyang County section in Shaanxi Province.

Study area

The selected highway from the city of Hanzhong to Lueyang County section is located in the south of Shaanxi Province, China (Fig. 2). The route starts at Xiejiaying Village, Chenggu County, Hanzhong City

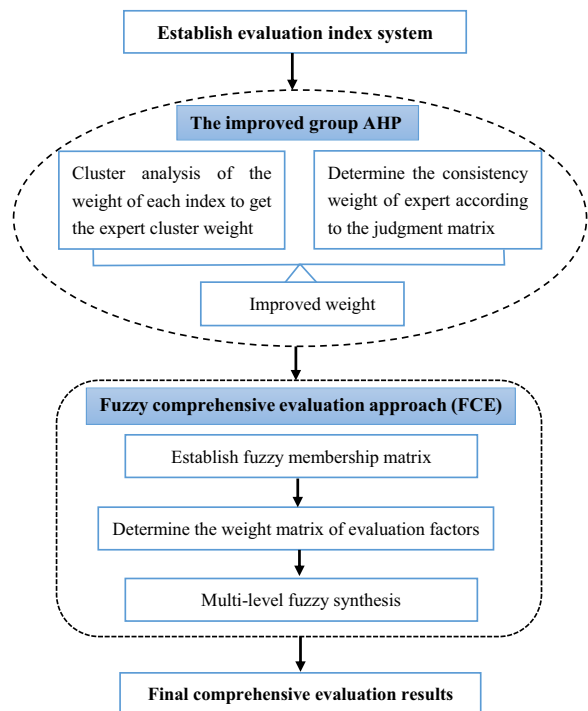


Fig. 1 The assessment process of the improved group AHP-FCE model

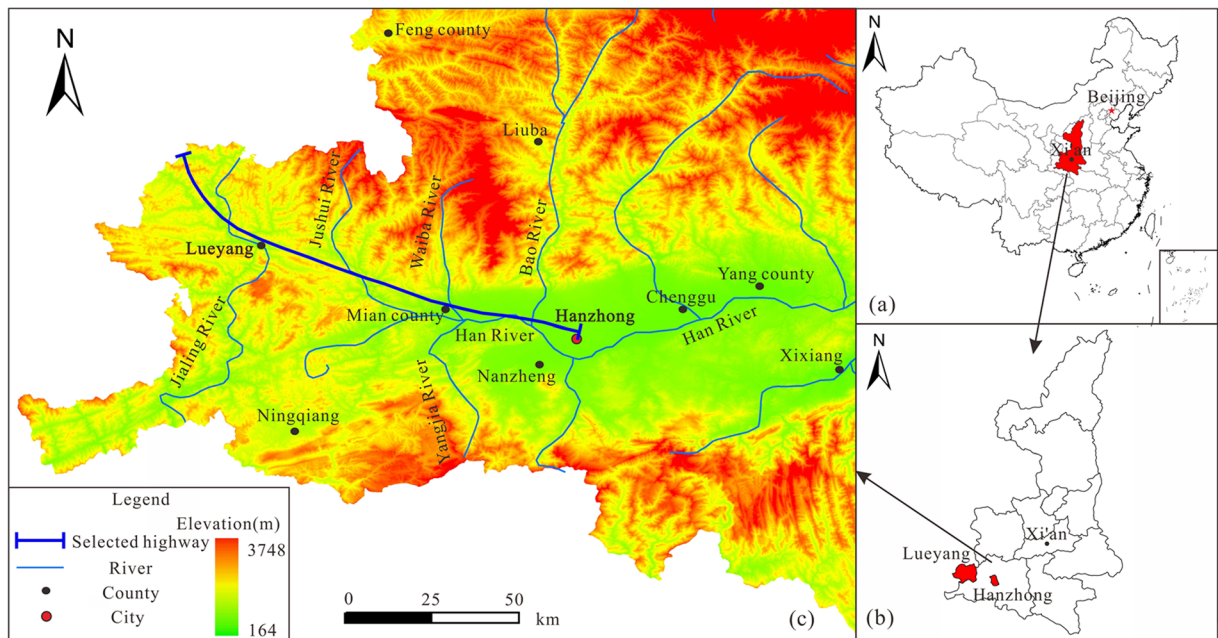


Fig. 2 Location and terrain of the study area

(107° 13' N, 33° 4' E) and ends at Dashibei Village, Baishuijiang Town, Lueyang County (106° 4' N, 33° 37' E). It is located in Qinba mountain area. The total length of the project is 154.02 km, with 197 bridges in total, including 4 super bridges, 157 major bridges, 36 medium and small bridges, and 207 culverts. There are 50 tunnels in the whole line, including 2 very long tunnels, 4 long tunnels, 9 medium tunnels, and 35 short tunnels, accounting for 56.38% of the total length of the line. A total of 10 interconnecting interchanges are arranged along the entire line, and its connecting lines have 7 locations.

Establishing indicators system

The environmental impact assessment of highway construction had multiple objectives and multiple levels. This paper combined the comprehensive and hierarchical principles, previous research results (Robinson et al. 2010; Jaeger et al. 2005; Jaeger et al. 2006; Coffin 2007), and expert opinions and the characteristics of the highways from the city of Hanzhong to Lueyang County section in Shaanxi Province to establish an ecological environment impact index system, including the 6 main factors of the social environment (A_1), ecological environment (A_2), acoustic environment (A_3), surface water environment (A_4), groundwater

environment (A_5) and air environment (A_6), and 22 sub-factors, as shown in Fig. 3.

Quantifying assessment indicators

Quantifying qualitative indicators

This paper used the assessment grade membership method (X. Xu 2006) to quantify the qualitative indicators. First, set the set of qualitative indicators: $M = \{m_1, m_2, \dots, m_n\}$, where m_1, m_2, \dots, m_5 were qualitative indicators to be evaluated. To determine the degree of influence of each indicator, we referred to the “five equal division” method of evaluation grade (Cao 2013). In this research, the indices data were normalized to [0-1], and then, the evaluation values were divided into five grades. Accordingly, $V = (V_1, V_2, V_3, V_4, V_5)$ corresponded to the five grades: {lower, low, medium, high, and higher}. Assign a value to each grade to turn qualitative evaluation into quantitative evaluation, that is, $V_1 = 0.2$, $V_2 = 0.4$, $V_3 = 0.6$, $V_4 = 0.8$, and $V_5 = 1.0$. Finally, the expert survey method was used to determine the membership of the element of m_i in the set. There were five qualitative indicators in this article: the impact on regional development planning (A_{11}), the demolition and resettlement impact (A_{12}), the impact

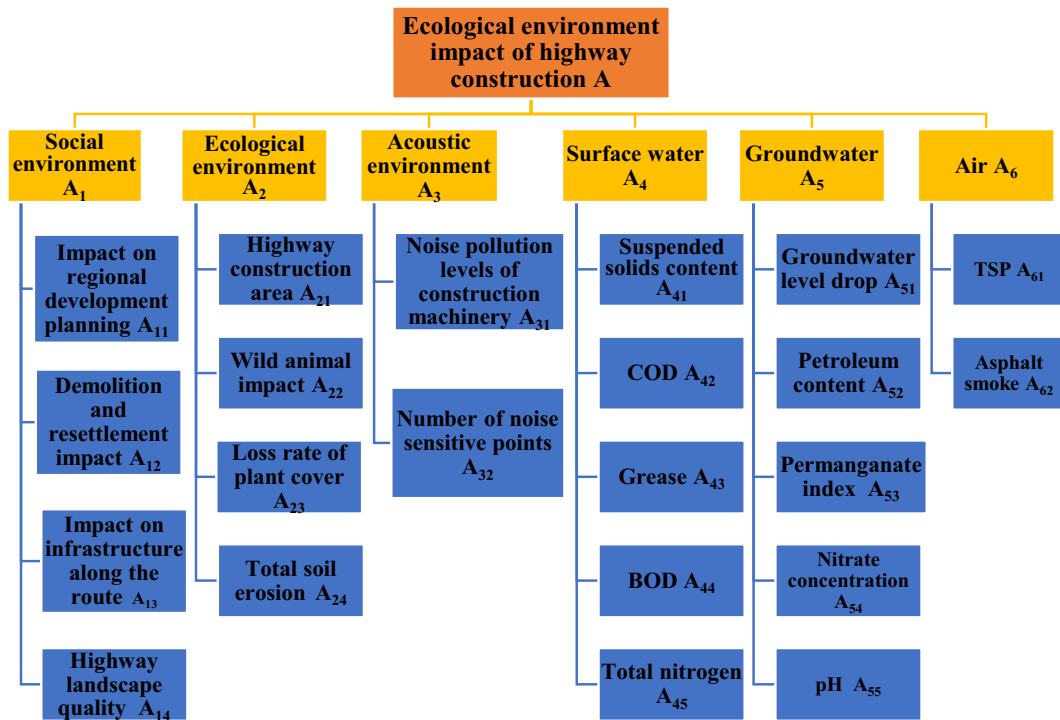


Fig. 3 Hierarchical impact assessment framework for highway construction

on infrastructure along the route (A_{13}), the wild animal impact (A_{22}), and the groundwater level drop (A_{51}). Ten experts were organized to express their opinions on the surveyed indicators and then to calculate the results, as shown in Table 1.

By normalizing the elements n_{ij} in the matrix and adopting the equal specific gravity method (X. Xu 2006), the fuzzy membership degree of the evaluation index can be obtained by the equation $r_{ij} = n_{ij}/n$, and then the fuzzy membership matrix R can be obtained.

Table 1 Determination of the membership degree of qualitative evaluation indicators

Assessment index	Assessment level V					Number of experts n
	V_1	V_2	V_3	V_4	V_5	
m_1	8	2	0	0	0	10
m_2	0	4	6	0	0	
m_3	0	0	6	4	0	
m_4	0	0	5	5	0	
m_5	0	7	3	0	0	

Quantifying and non-dimensionalizing quantitative indicators

Dimensionless processing was to normalize the values of evaluation indicators, which mainly included linear, polygonal, and curved dimensionless methods (Tu 2016). This paper used a linear dimensionless method. When the actual value of the indicator was converted into a standard value, the two were converted into a linear proportional relationship. The evaluation indicators in this paper can be divided into two types: large value type and small value type. Large value indicator was that bigger was better, such as highway landscape quality (A_{14}). Small value indicators were that smaller was better, such as loss rate of plant cover (A_{23}), total soil erosion (A_{24}), and BOD (A_{44}).

The dimensionless value of the index was S_i , $S_i \in [0, 1]$. The assessment index set was V and the assessment indicator $v_i \in V$. The indicator attribute value was x_i . The assessment standard had a maximum value of M_i and a minimum value of m_i . The equations were shown in (1), (2), and (3). $r_i = v_d(x_i), i = 1, 2, \dots, n$ (1)

The smaller the better type

$$r_i = v_d(x_i) = \begin{cases} 1 & , x_i \leq m_i \\ \frac{x_i - M_i}{M_i - m_i} & , x_i \in [m_i, M_i] \\ 0 & , x_i \geq M_i \end{cases} \quad (2)$$

The bigger the better type

$$r_i = v_d(x_i) = \begin{cases} 0 & , x_i \leq m_i \\ \frac{M_i - x_i}{M_i - m_i} & , x_i \in [m_i, M_i] \\ 1 & , x_i \geq M_i \end{cases} \quad (3)$$

Traditional fuzzy AHP approach

The traditional fuzzy AHP approach was established based on a four-step process (X. Wang et al. 2019):

Step 1: Establishment of factor set and assessment set

The factor set was a fuzzy set composed of various factors of the indicator, $A = (A_1, A_2, \dots, A_m)$. An assessment set was a collection of various assessment results, $V = (V_1, V_2, \dots, V_5)$.

Step 2: Calculation of single index

This paper used the triangular membership function to determine the membership of each indicator (Laarhoven and Pedrycz 1983), which was defined as shown in Fig. 4.

The $\{r_1, r_2, \dots, r_i\}$ in Fig. 4 was the set of assessment levels, and the membership function was obtained as follows:

$$f(x) = \begin{cases} 1 & , r_{\min} \leq x \leq r_1 \\ \frac{(x - r_{i-1})}{r_i - r_{i-1}} & , r_{i-1} \leq x \leq r_i \\ 0 & , \text{Other} \\ \frac{(r_{i+1} - x)}{r_{i+1} - r_i} & , r_i \leq x \leq r_{i+1} \\ 1 & , r_4 \leq x \leq r_{\max} \end{cases} \quad (4)$$

After the calculation of a single-index measure, the single-index measure evaluation matrix was as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \dots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix}$$

Step 3: Determination of indicator weight

The AHP approach was used to quantitatively describe the importance of each index factor. The 1–9 scale method (Lian and Cai 2012) was used to compare the impact degree of the index and establish a judgment matrix. Then, after consistency test, the weight set of each index factor was $W = (w_1, w_2, \dots, w_n)$, and $\sum_{i=1}^n w_i = 1$.

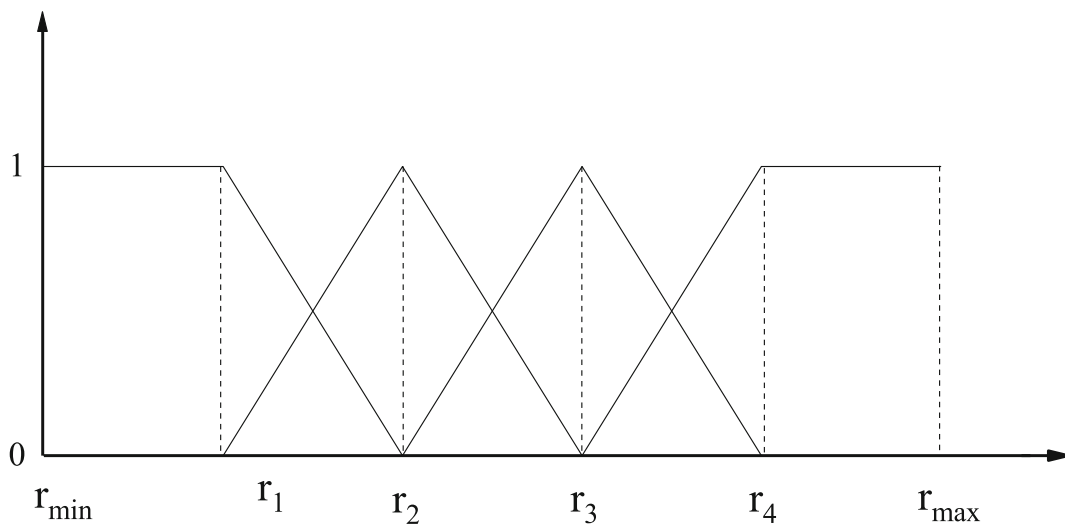


Fig. 4 Triangle membership function

Step 4: Multi-level fuzzy comprehensive operation

After calculating the single-index measure evaluation matrix by the equation, the weight matrix for each index can be obtained by matching the corresponding index weight calculation method. Then, the multi-index comprehensive evaluation matrix was obtained by multiplying the single-index evaluation matrix and the corresponding weight matrix. The calculated equation was as follows:

$$A_i = W_i * R_i \tag{5}$$

Where A_i was the comprehensive evaluation matrix, and W_i was the weight of index, and R_i was the single-index matrix.

Improved fuzzy AHP approach

Determination of weights

The traditional fuzzy AHP approach used the AHP to determine the weight of index, which had greater subjectivity and uncertainty. Therefore, this paper used the improved group AHP approach instead of the AHP to determine the index weight. The improved approach combined quantitative and qualitative analysis, which not only respected the result of individual judgment and its accuracy, but also paid attention to the comprehensive opinions of the group.

The determination of the weight of the improved approach (Xia et al. 2011) was based on the traditional AHP approach. First, establish a hierarchical model, construct a judgment matrix, calculate a judgment matrix, and check consistency. Through the previous steps, the weight given by each expert to the indicator was obtained, and the weight that cannot be used for analysis was eliminated.

Secondly, the eigenvalues of the individual judgment matrix were used to reflect the influence of each expert on the integrated ranking vector change, and the consistency degree of the construction judgment matrix for expert can be calculated accordingly by Eq. (6).

$$F_i = (m + 2) - (\lambda_{max})_i \tag{6}$$

Where F_i was the consistency degree of the construction judgment matrix for experts. The m was the order of

the judgment matrix. λ_{max} was the largest eigenvalue of the judgment matrix constructed by the experts.

Thirdly, we took individual vectors that passed several expert consistency tests as samples, and performed cluster analysis. This paper used SPSS (version 22.0) to perform systematic clustering on several experts, and calculated the weights of several experts based on the clustering results combined with Eq. (7).

$$\lambda_i = \frac{\varphi_p}{\sum_{p=1}^t \varphi_p^2} \tag{7}$$

Where λ_i was the weight of the expert i . The t was the number of categories of individual sorting vectors. The φ_p was the class capacity, that is, the number of individual vectors contained in the p class.

Finally, determining the comprehensive weight of the expert was to combine the consistency degree of the judgment matrix constructed by the expert with the class capacity expression information of each category by Eq. (8). Then, K_i' was normalized to obtain the final expert weight K_i .

$$K_i' = F_i * \lambda_i \tag{8}$$

$$K_i = \frac{K_i'}{\sum_{i=1}^n K_i'} \tag{9}$$

Sum each column weight, and finally get the new weight of the indicator.

$$W_j = \sum_{i=1}^n K_i W_{ij} \quad (i = 1, 2, \dots, 10, j = 1, 2, \dots, 6) \tag{10}$$

Where W_j was the new weight of the indicator j . K_i' was the combined weight of the expert i . W_{ij} was the weight of the expert i to the indicator j . Then, calculated the new weight of the remaining indicators by Eq. (10).

Secondary situation assessment of multi-index

The traditional fuzzy AHP approach usually used first-level assessment, which treated each influencing factor as a whole. Due to the data distribution, characteristics of each factor had a negligible impact on the evaluation results. This paper used a secondary-level assessment model and determined weights with an improved group AHP approach. Other steps of multi-index secondary situation assessment were the same as the traditional fuzzy AHP approach described in the “[Traditional fuzzy AHP approach](#)” section.

Results and discussion

Assignment and normalization of indicators

The environmental impact index of highway construction was mainly obtained through the field research of Chang’an University Environmental Engineering Research Institute and relevant departments. Based on the actual situation of the city of Hanzhong to Lueyang County highway and the environmental conditions of the county and city, the maximum and minimum evaluation index of each quantitative index were given. According to Eqs. (2) and (3), the index was dimensionless to obtain the normalized value, as shown in Table 2.

Establishment of fuzzy evaluation matrix

In this research, we referred to the “five equal division” method of evaluation grade (Cao 2013) and the indices

data were standardized and normalized to the interval of [0, 1], and then, the evaluation values were divided into five grades. Accordingly, $V = (V_1, V_2, V_3, V_4, V_5)$ corresponded to the five grades: {lower, low, medium, high, and higher}. Assign a value to each grade to turn qualitative evaluation into quantitative evaluation, that is, $V_1 = 0.2, V_2 = 0.4, V_3 = 0.6, V_4 = 0.8,$ and $V_5 = 1.0$. The evaluation matrix were calculated according to the normalized values in Table 2 and Eq. (4) of the membership, as shown in Table 3.

Calculation of weight

Traditional AHP approach to determine weight

The fifteen experts (including professors, senior engineers, and graduate students) in the field of highway environment were invited to judge the importance of each indicator. With the help of yaahp software (version

Table 2 Normalized value of the index

Main factors	Sub-factors	Attribute value	Index maximum	Index minimum	Normalized value
Social environment A ₁	Impact on regional development planning A ₁₁	–	–	–	0.2400
	Demolition and resettlement impact A ₁₂	–	–	–	0.5200
	Impact on infrastructure along the route A ₁₃	–	–	–	0.6800
	Highway landscape quality A ₁₄ (%)	61.02	100	30	0.4431
Ecological environment A ₂	Highway construction area A ₂₁ (hm ²)	985.76	1074.61	645.83	0.7928
	Wild animal impact A ₂₂	–	–	–	0.7000
	Loss rate of plant cover A ₂₃ (%)	73.95	100	10	0.7106
	Total soil erosion A ₂₄ (t/(km ² ·a))	4500	8000	500	0.5333
Acoustic environment A ₃	Noise pollution levels of construction machinery A ₃₁ (dB)	69.14	72	66	0.5233
	Number of noise sensitive points A ₃₂	12	45	6	0.1538
Surface water A ₄	Suspended solids content A ₄₁ (mg/L)	100	200	70	0.2308
	COD A ₄₂ (mg/L)	250	300	150	0.6667
	Grease A ₄₃ (mg/L)	50	100	30	0.2857
	BOD A ₄₄ (mg/L)	110	150	30	0.6667
	Total nitrogen A ₄₅ (mg/L)	20	25	25	0.5000
Groundwater A ₅	Groundwater level drop A ₅₁	–	–	–	0.4600
	Petroleum content A ₅₂ (mg/L)	10	15	8	0.2857
	Permanganate index A ₅₃	9	15	2	0.5385
	Nitrate concentration A ₅₄ (mg/L)	21	30	2	0.6786
	pH A ₅₅	6.8	8.5	6.5	0.1500
Air A ₆	TSP A ₆₁ (mg/m ³)	0.28	0.3	0.15	0.8667
	Asphalt smoke A ₆₂ (mg/m ³)	43.7	80	10	0.4814

“–” represents a qualitative indicator; the evaluation attribute value refers to the “Quantifying qualitative indicators” section

Table 3 Fuzzy evaluation matrix of the index

Main factors	Lower	Low	Medium	High	Higher
Social environment A_1	0.8000	0.2000	0	0	0
	0	0.4000	0.6000	0	0
	0	0	0.6000	0.4000	0
	0	0.7845	0.2155	0	0
Ecological environment A_2	0	0	0	0.0360	0.9640
	0	0	0.5000	0.5000	0
	0	0	0.4470	0.5530	0
	0	0.3335	0.6665	0	0
Acoustic environment A_3	0	0.3835	0.6165	0	0
	1	0	0	0	0
Surface water A_4	0.8460	0.1540	0	0	0
	0	0	0.6665	0.3335	0
	0.5715	0.4285	0	0	0
	0	0	0.6665	0.3335	0
Groundwater A_5	0	0.5	0.5000	0	0
	0	0.7000	0.3000	0	0
	0.5715	0.4285	0	0	0
	0	0.3075	0.6925	0	0
Air A_6	0	0	0.6070	0.3930	0
	1	0	0	0	0
	0	0	0	0.6665	0.3335
	0	0.5930	0.4070	0	0

10.1), an assessment index model was constructed, and the weight and consistency test given by each expert to the main factors were calculated. When $CR < 0.1$, the consistency test was qualified; otherwise, it was not qualified (Saaty 1980). The weights of the main factors

by the experts have passed the consistency test, as shown in Table 4.

The weight value of the same index that has pass the consistency test was arithmetically averaged, and the traditional comprehensive weight representing the

Table 4 Empowerment of main factors and consistency ratio

Expert number	W'_1	W'_2	W'_3	W'_4	W'_5	W'_6	λ_{max}	CR
1	0.0676	0.2684	0.163	0.1034	0.177	0.2206	6.4051	0.0643
2	0.3328	0.1121	0.0834	0.1109	0.1915	0.1693	6.1831	0.0291
3	0.1858	0.474	0.0569	0.1045	0.1045	0.0744	6.1988	0.0316
4	0.1829	0.1477	0.0472	0.3112	0.0806	0.2304	6.3051	0.0484
5	0.3564	0.2143	0.0419	0.1018	0.1825	0.1031	6.3118	0.0495
6	0.3201	0.1093	0.0511	0.187	0.2557	0.0768	6.2372	0.0376
7	0.3539	0.2408	0.0377	0.114	0.1794	0.0742	6.2655	0.0421
8	0.0621	0.26	0.0372	0.275	0.2958	0.0699	6.3089	0.0490
9	0.1098	0.3837	0.0506	0.1467	0.216	0.0932	6.4105	0.0652
10	0.394	0.2388	0.0542	0.0976	0.0871	0.1283	6.3028	0.0481

opinions of all experts was obtained. Similarly, the traditional weights of secondary indicators were determined, as shown in Table 5.

Improve group AHP approach to determine weight

Based on the traditional weights of the ten experts calculated in the previous section, then use SPSS software to perform systematic clustering, and cluster into four categories at a distance of 16 as shown in Fig. 5. The first category had five experts, which numbered 5, 7, 10, 2, and 6. The second category had one expert, which numbered 4, and the third category had three experts, which numbered 3, 9, and 1. There was one expert in category four and the number was 8.

Combined with the results of the classification, the expert weights were calculated according to Eq. (6), and the improved weights of the main factors were further calculated according to Eqs. (7), (8), (9), and (10). In the same way, calculate the improved weight of sub-factors, and the results were shown in Table 6.

Results of comprehensive evaluation

According to Eq. (5) and the data in Tables 3 and 6, the first-level fuzzy evaluation results were calculated, as shown in Table 7. As can be seen from Table 7, the degree of influence of highway construction on each of the main factors was different.

In the whole assessment process of quantitative analysis, by calculating the assessment value of the main factors, we can understand the impact of highway construction on the environmental factors, which was conducive to making timely and appropriate decisions for the adverse impact of environmental factors. Figure 6 clearly showed the main factors under different degrees of influence. As can be seen, the impact level of highway construction on social factors and acoustic factors was “lower,” the impact on ecological factors, surface water, and groundwater factors was “medium,” and the impact on air factors was “high.” Therefore, environmental protection measures can be taken to control the factors with greater impact.

Finally, according to the first-level fuzzy situation assessment results and the improved weight values in

Table 5 Traditional weight values of the index

Main factors	Traditional weight	Sub-factors	Traditional weight
Social environment A_1	0.2365	Impact on regional development planning A_{11}	0.4023
		Demolition and resettlement impact A_{12}	0.2092
		Impact on infrastructure along the route A_{13}	0.1991
		Highway landscape quality (%) A_{14}	0.1894
Ecological environment A_2	0.2449	Highway construction area A_{21}	0.1119
		Wild animal impact A_{22}	0.2741
		Loss rate of plant cover (%) A_{23}	0.3427
		Total soil erosion A_{24}	0.2713
Acoustic environment A_3	0.0623	Noise pollution levels of construction machinery A_{31}	0.4417
		Number of noise sensitive points A_{32}	0.5583
Surface water A_4	0.1552	Suspended solids content A_{41}	0.0813
		COD A_{42}	0.2953
		Grease A_{43}	0.1535
		BOD A_{44}	0.1806
		Total nitrogen A_{45}	0.2893
Groundwater A_5	0.1770	Groundwater level drop A_{51}	0.2636
		Petroleum content A_{52}	0.1764
		Permanganate index A_{53}	0.2242
		Nitrate concentration A_{54}	0.1797
		pH A_{55}	0.1562
Air A_6	0.1240	TSP A_{61}	0.5117
		Asphalt smoke A_{62}	0.4883

Fig. 5 Dendrogram of variables of cluster analysis

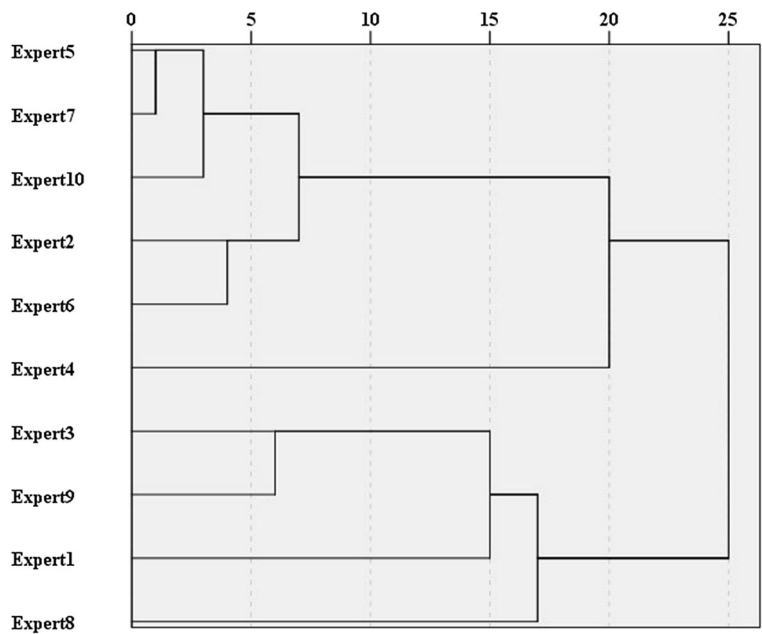


Table 6 Improved weight values of the index

Main factors	Improved weight	Sub-factors	Improved weight
Social environment A ₁	0.2835	Impact on regional development planning A ₁₁	0.4302
		Demolition and resettlement impact A ₁₂	0.1815
		Impact on infrastructure along the route A ₁₃	0.2117
		Highway landscape quality (%) A ₁₄	0.1766
Ecological environment A ₂	0.2308	Highway construction area A ₂₁	0.1069
		Wild animal impact A ₂₂	0.2600
		Loss rate of plant cover (%) A ₂₃	0.3776
		Total soil erosion A ₂₄	0.2556
Acoustic environment A ₃	0.0618	Noise pollution levels of construction machinery A ₃₁	0.4167
		Number of noise sensitive points A ₃₂	0.5833
Surface water A ₄	0.1307	Suspended solids content A ₄₁	0.0847
		COD A ₄₂	0.3092
		Grease A ₄₃	0.1425
		BOD A ₄₄	0.1717
		Total nitrogen A ₄₅	0.2919
Groundwater A ₅	0.1764	Groundwater level drop A ₅₁	0.3008
		Petroleum content A ₅₂	0.1463
		Permanganate index A ₅₃	0.2340
		Nitrate concentration A ₅₄	0.1924
Air A ₆	0.1169	pH A ₅₅	0.1267
		TSP A ₆₁	0.5730
		Asphalt smoke A ₆₂	0.4270

Table 7 Result of the first level evaluation

Main factors	Lower	Low	Medium	High	Higher
Social environment A_1	0.3442	0.2972	0.2740	0.0847	0.0000
Ecological environment A_2	0.0000	0.0852	0.4691	0.3426	0.1031
Acoustic environment A_3	0.5833	0.1598	0.2569	0.0000	0.0000
Surface water A_4	0.1531	0.2201	0.4665	0.1604	0.0000
Groundwater A_5	0.2103	0.3452	0.3690	0.0756	0.0000
Air A_6	0.0000	0.2532	0.1738	0.3819	0.1911

Table 6, the second level assessment results were shown in Table 8.

According to the principle of maximum membership, $0.3482 \in [0.4, 0.6]$, the secondary situation assessment level was “medium,” that is, the impact of the selected section of highway construction on the ecological environment was general, which was consistent with the

actual situation of environmental impact of highway construction.

In summary, the highway construction behavior had more impact on the ecological environment safety. The traditional environmental impact assessment only considered water, atmosphere, noise, solid waste, and other factors, which was not comprehensive. In order to

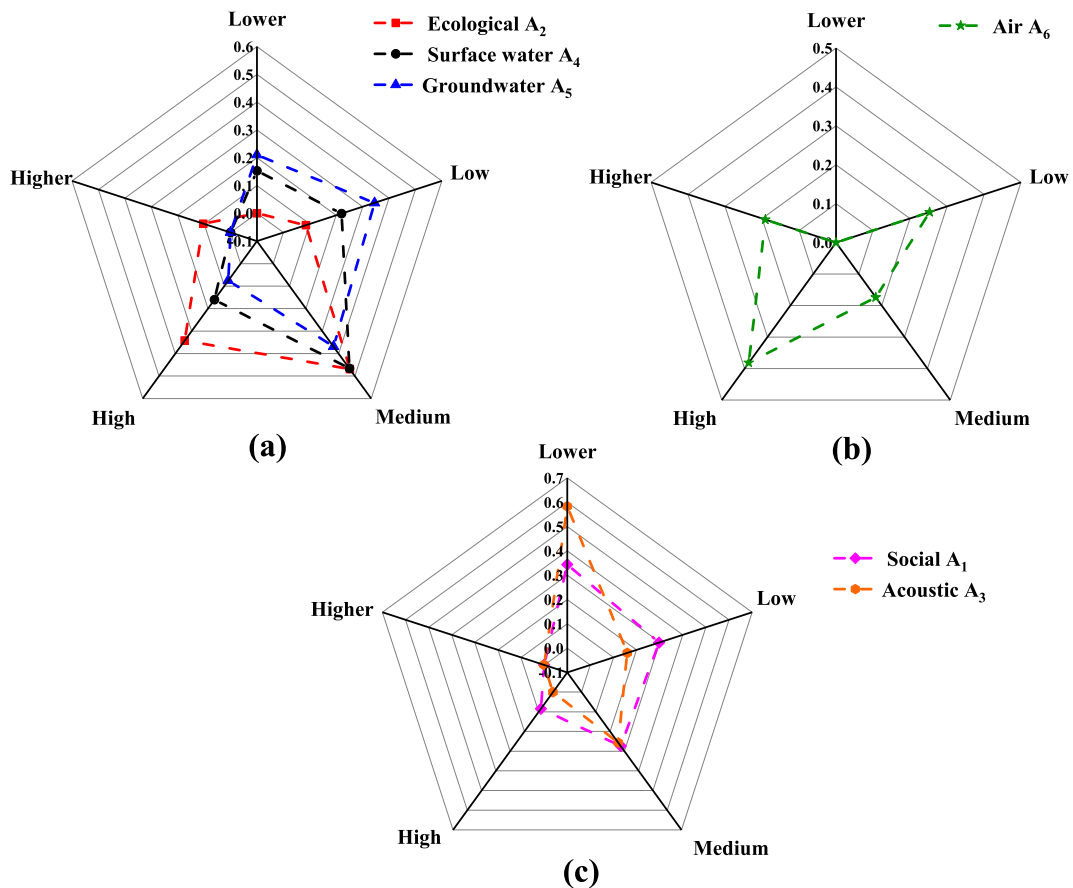


Fig. 6 Distribution of assessment levels of major factors on environmental impact. **a** Medium impact factors; **b** High impact factors; **c** Lower impact factor

Table 8 Result of the second level evaluation

Assessment level	Lower	Low	Medium	High	Higher
Membership	0.1907	0.2330	0.3482	0.1820	0.0238

objectively assess the ecological environment impact of highway projects, the ecological impact factors must be fully considered. Therefore, an effective and scientific ecological environment impact assessment method was established, which adapted to the current ecological environment. The results showed that the established ecological environment evaluation index system and method were very successful. It overcame the shortcomings of equal weight average in traditional methods, highlighted the importance of individual indicators, and made the evaluation results more accurate and objective.

Comparison of traditional and improved approaches

Comparison of weight values

When the traditional AHP approach was used to identify and rank the weight values of the main factors (Table 9), it can be seen that the ecological factor ranked first, and the social factor ranked second, but the result of each other was very close, which indicated that the importance of two factors in the traditional AHP approach was almost equal to each other. Our study results were partially similar to those of Hatefi et al. (Hatefi and Tamošaitienė 2018). In the improved approach, the social factor showed the highest weight, followed by the ecological factor. Compared with traditional approach, it highlighted the importance of social factor in the assessment. This was consistent with the actual situation of the environmental impact of the highway

construction project. Most studies often only focused on the impact of ecological factor and ignored the social factor. The present assessments in China emphasized particularly on the effect of the natural environment, leaved a blank on the social environment (W. Wang 2009). Therefore, the improved approach emphasized the importance of social factor, and overcame the shortcomings of equal treatment of expert opinions in traditional approaches.

Assessment of the sub-factors with respect to the main factors showed that only the ordering of the sub-factor weights under social factors has changed with the improved approach, and the weight values of the sub-factors under the other main factors have changed but the ranking has not changed. Impact on regional development planning was the most important sub-factor under social factors in two approaches (Table 10). In traditional approach, demolition and resettlement impact was in the second place and impact on infrastructure along the route was in the third place although it was in the second place with the improved approach. This indicated that impact on infrastructure along the route factor was more important than demolition and resettlement impact factor which was also consistent with the actual situation. Relevant literature research (L. Xu et al. 2010) showed that the weight ratio of demolition and resettlement impact factor was only 0.042, which was relatively small. It indicated that this factor did not have a great impact on the environment.

Loss rate of plant cover was the most important sub-risk factors under ecological factors which was

Table 9 Weight rankings for main factors

Main factors	Traditional weight	Rank	Improved weight	Rank
Social environment A ₁	0.2365	2	0.2835	1
Ecological environment A ₂	0.2449	1	0.2308	2
Acoustic environment A ₃	0.0623	6	0.0618	6
Surface water A ₄	0.1552	4	0.1307	4
Groundwater A ₅	0.1770	3	0.1764	3
Air A ₆	0.1240	5	0.1169	5

Table 10 Weight rankings for sub-factors

Sub-factors	Traditional weight	Rank	Improved weight	Rank
Impact on regional development planning A ₁₁	0.4023	1	0.4302	1
Demolition and resettlement impact A ₁₂	0.2092	2	0.1815	3
Impact on infrastructure along the route A ₁₃	0.1991	3	0.2117	2
Highway landscape quality (%) A ₁₄	0.1894	4	0.1766	4
Highway construction area A ₂₁	0.1119	4	0.1069	4
Wild animal impact A ₂₂	0.2741	2	0.2600	2
Loss rate of plant cover (%) A ₂₃	0.3427	1	0.3776	1
Total soil erosion A ₂₄	0.2713	3	0.2556	3
Noise pollution levels of construction machinery A ₃₁	0.4417	2	0.4167	2
Number of noise sensitive points A ₃₂	0.5583	1	0.5833	1
Suspended solids content A ₄₁	0.0813	5	0.0847	5
COD A ₄₂	0.2953	1	0.3092	1
Grease A ₄₃	0.1535	4	0.1425	4
BOD A ₄₄	0.1806	3	0.1717	3
Total nitrogen A ₄₅	0.2893	2	0.2919	2
Groundwater level drop A ₅₁	0.2636	1	0.3008	1
Petroleum content A ₅₂	0.1764	4	0.1463	4
Permanganate index A ₅₃	0.2242	2	0.2340	2
Nitrate concentration A ₅₄	0.1797	3	0.1924	3
pH A ₅₅	0.1562	5	0.1267	5
TSP A ₆₁	0.5117	1	0.5730	1
Asphalt smoke A ₆₂	0.4883	2	0.4270	2

consistent with Zhang et al. (X. Zhang et al. 2012). The higher the loss rate of plant cover, the greater the damage to the ecological environment during the construction period. COD was the most important sub-risk factors under surface water factors. Zhang et al. (G. Zhang et al. 2015) pointed out that the main reason for the increase of COD was the domestic sewage produced during the construction of the highway. In groundwater factors, groundwater level drop had the greatest impact on the environment. However, the decrease of groundwater level will lead to the collapse of subgrade, the drying of vegetation, and so on. In air environment factors, TSP was the most important factors. This was mainly due to dust coming out from mixing plant, and smoke coming out from the small-scale automobile on the road, carrying of construction materials like sand, bricks, stone chips, and cement in open trucks and vehicular movements on highways (Singh et al. 2017). In recent years, public awareness has increased regarding the environmental impacts of road construction (Gumus et al. 2008). However, the most important thing

in assessing the impact of highway construction on the environment was to consider the combined impacts of society and nature.

Comparison of comprehensive assessment results

Compared with the improved approach and the traditional fuzzy AHP, the assessment results were shown in Fig. 7. The result of this project using traditional assessment approach was “medium.” It can be seen that the results obtained by the improved approach in this paper were consistent with the traditional approach, indicating that it was feasible to use the improved group AHP-FCE approach to assess the environmental impact of the highway construction period. However, in the traditional approach, the subjective judgment and selection preference of the experts had a great impact on the results, while in the improved approach, combining with the consistency of each expert’s judgment matrix and the idea of cluster analysis, the opinions of experts have been considered more comprehensively and

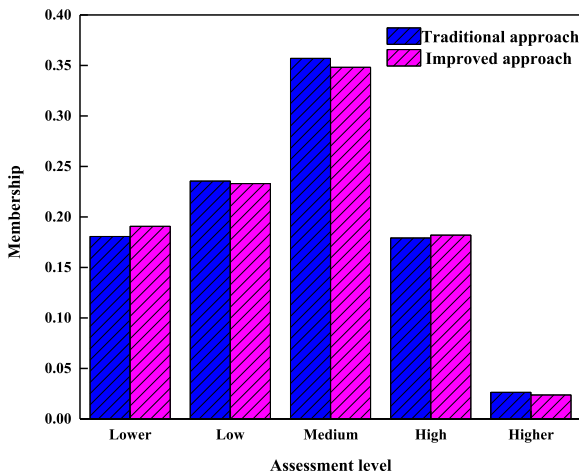


Fig. 7 Comparison of assessment results

meticulously, and some subtle impacts have been more accurately judged, and the status of some important indicators in the entire system can be effectively highlighted, thereby ensuring the objectivity and reliability of the environmental impact assessment results of highway construction project.

For the overall analysis, the improved group AHP-FCE approach systematically considered various factors, made full use of various information, better highlighted the status of some important indicators in the whole system, and could more comprehensively reflect the true status of the highway construction projects. Moreover, it had more pertinence and guidance for the plan adjustment and measures implementation of environmental impact of highway construction projects, which showed that the model has strong operability and better practicability.

Protective measures

According to the characteristics of the ecological environment along the Hanzhong to Lueyang section of the road, combined with the assessment results of this study, the factors that had a greater impact on the social environment were impact on regional development planning factor (A_{11}), demolition and resettlement impact factor (A_{12}), and impact on infrastructure along the route factor (A_{13}). In the ecological environment, the loss rate of plant cover (A_{23}) was the most important factor, followed by the wild animal impact factor (A_{22}). In the surface water environment, COD (A_{42}) was the most

important factor. In the groundwater environment, groundwater level drop (A_{51}) had the greatest impact on the environment. In the air, TSP (A_{61}) had the greatest impact on the environment. In order to coordinate the development of highway construction and the ecological environment, the following protection measures were proposed from the five aspects of social, ecological, water, acoustic, and air environment in combination with these specific impacts.

Social environment

Try to occupy less arable land and rely on the governments along the line to do a good job in land acquisition. Make preparations before construction to ensure the normal life of residents.

Ecological environment

First, construction should be standardized. Secondly, soil erosion and wildlife protection should be strictly protected. In the end, the topsoil backfill will be implemented as soon as possible and the vegetation will be restored.

Water resource

Set up a sedimentation tank to treat this part of the wastewater to the standard, and all the treated wastewater will be reused for equipment washing and dust prevention.

Acoustic environment

Try to select low-noise construction machinery and technology. The operation time with strong noise source can be put in the daytime (06:00-22:00) or adjusted appropriately. The construction road shall be far away from sensitive points such as residential areas and schools.

Air environment

The place where dust was generated shall be watered regularly, such as construction road and waste slag plant. During the construction stage, the temporary access road shall be hardened and the transportation of powdery materials shall be covered. For the construction of asphalt pavement, the asphalt concrete mixing plant was located in the downwind direction outside the environmental sensitive points such as residential areas and schools.

Conclusions

In this study, an index evaluation system using a combination of improved group AHP and FCE model was established for the first time. The model applying case was confirmed the accuracy and scientificity, and based on the evaluation results, corresponding protection measures were proposed for the construction project. The following conclusions were drawn:

1. An improved group AHP-FCE model was proposed and a second-level evaluation model was established. A total of six main factors and 22 sub-factors were identified, including social environment (A_1), ecological environment (A_2), acoustic environment (A_3), surface water environment (A_4), groundwater environment (A_5), and air environment (A_6).
2. The improved group AHP approach was applied to determine the weight of evaluation index. It combined the consistency of matrix with cluster analysis, which not only respected the result of individual judgment and its accuracy, but also paid attention to the comprehensive opinions of the group. It overcame the equal weight distribution of traditional approach, which made the overall weight ratio distribution more reasonable and objective.
3. This model was applied to the case study of ecological environment impact assessment of the highway construction project from the city of Hanzhong to Lueyang County in Shaanxi Province. The weight of social factor determined by the improved approach was 0.2835, while that of the traditional approach was only 0.2365, and the weight difference was 0.047. This approach highlighted the importance of social factor and overcame the equal

weight distribution of traditional approach, which made the overall weight ratio distribution more reasonable and objective. The comprehensive assessment result was 0.3482, which was in line with the “general impact” level. This was consistent with the actual situation of highway construction. The improved group AHP-FCE model could be used successfully for assessing the impact of the ecological environment in highway construction, and it had good applicability and popularization value in ecological environment assessment. The study results will also enable highway managers and designers to compare the weight rankings of relevant impact factors and take targeted precautions accordingly.

Acknowledgments The authors are also thankful to all experts involved for their valuable outputs and help.

Funding information This research was funded by the National Key Research and Development Program of China (No. 2016YFC0400701), the National Natural Science Foundation of China (No. 41977163 and No. 41672224), Henan Province Transportation Science and Technology Project (No. 2020G-2-10 and No. 2017J4-1), and the Natural Science Foundation of Shaanxi Province (No. 2019JM-428).

References

- Akay, A. O., Demir, M., & Akgul, M. (2018). Assessment of risk factors in forest road design and construction activities with fuzzy analytic hierarchy process approach in Turkey. *Environmental Monitoring and Assessment*, 190(9), 561. <https://doi.org/10.1007/s10661-018-6948-0>.
- Aminbakhsh, S., Gunduz, M., & Sonmez, R. (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. *Journal of Safety Research*, 46, 99–105. <https://doi.org/10.1016/j.jsr.2013.05.003>.
- Cao, W. (2013). *Study on the economic impact of flood disasters and the ability of disaster prevention and mitigation*. Changsha: Hunan University (In Chinese).
- Coffin, A. W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. *Journal of Transport Geography*, 15(5), 396–406.
- Deng, H. (1999). Multicriteria analysis with fuzzy pairwise comparison. *International Journal of Approximate Reasoning*, 21(3), 215–231. [https://doi.org/10.1016/S0888-613X\(99\)00025-0](https://doi.org/10.1016/S0888-613X(99)00025-0).
- Gao, J., & Li, J. (2004). Application of gray relation analysis to location of logistics center. *Industrial Engineering Journal*, 7(3), 44–46.

- Gumus, S., Acar, H. H., & Toksoy, D. (2008). Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. [journal article]. *Environmental Monitoring and Assessment*, 142(1), 109–116. <https://doi.org/10.1007/s10661-007-9912-y>.
- Han, R., Zhou, B., An, L., Jin, H., Ma, L., Li, N., Xu, M., & Li, L. (2019). Quantitative assessment of enterprise environmental risk mitigation in the context of Na-tech disasters. *Environmental Monitoring and Assessment*, 191(4), 210. <https://doi.org/10.1007/s10661-019-7351-1>.
- Hatefi, S. M., & Tamošaitienė, J. (2018). Construction projects assessment based on the sustainable development criteria by an integrated fuzzy AHP and improved GRA model. *Sustainability*, 10(4). <https://doi.org/10.3390/su10040991>.
- Huang, R. Y., & Yeh, C. H. (2008). Development of an assessment framework for green highway construction. *Journal of the Chinese Institute of Engineers*, 31(4), 573–585. <https://doi.org/10.1080/02533839.2008.9671412>.
- Jaeger, J. A. G., Bowman, J., Brennan, J., Fahrig, L., Dan, B., Bouchard, J., et al. (2005). Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling*, 185(2-4), 329–348.
- Jaeger, J. A. G., Fahrig, L., & Ewald, K. C. (2006). Does the configuration of road networks influence the degree to which roads affect wildlife populations? *Road Ecology Center*, 151–153.
- Jing, L. (2008). *The environmental evaluation index system of road*. Beijing Forestry University (In Chinese).
- Laarhoven, P. J. M. V., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems*, 11(1), 199–227.
- Lian, Y., & Cai, J. (2012). Application of Fengshui doctrines in landscape architecture design. *Journal of Landscape Research*.
- Lin, S.-Y., Lu, J.-L., & Fan, Y.-L. (2019). An ecological early warning indicator system for environmental protection of scenic areas. *Sustainability*, 11(8), 2344.
- Liu, H., & Wang, J. (2018). Vulnerability Assessment for cascading failure in the highway traffic system. *Sustainability*, 10(7), 2333.
- Lv, W., & Ji, S. (2019). Atmospheric environmental quality assessment method based on analytic hierarchy process. *Discrete and Continuous dynamical systems-Series S*, 12(4-5), 941–955. <https://doi.org/10.3934/dcdss.2019063>.
- Lyu, H.-M., Wu, Y.-X., Shen, J. S., & Zhou, A.-N. (2018). Assessment of social-economic risk of Chinese dual land use system using fuzzy AHP. *Sustainability*, 10(7), 2451.
- Nematollahi, S., Fakheran, S., & Soffianian, A. (2017). Ecological impact assessment of road networks at landscape scale using Spatial Road Disturbance Index (SPROADI). [Article]. *Journal of Environmental Engineering and Landscape Management*, 25(3), 297–304. <https://doi.org/10.3846/16486897.2016.1255218>.
- Qian, Y., Lei, J., & Xu, X. (2001). Negative impacts of Turpan-Urumqi-Dahuangshan highway construction on eco-environment and countermeasures. *Arid Land Geography*, 24(2), 165–171.
- Qizhou, H., & Hua-pu, L. Rough set comprehensive evaluation model for environmental security effect of highway construction projects. In 2009 International Conference on Energy and Environment Technology, 16-18 Oct. 2009 2009 (Vol. 1, pp. 301-304). <https://doi.org/10.1109/ICEET.2009.78>.
- Robinson, C., Duinker, P. N., & Beazley, K. F. (2010). A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads. *Environmental Reviews*, 18, 61–86. <https://doi.org/10.1139/a10-002>.
- Saaty, T. L. (1980). *The analytic hierarchy process: planning, priority setting, resource Allocation*. McGraw-Hill.
- Salvador, N. N. B., Glasson, J., & Piper, J. M. (2000). Cleaner production and environmental impact assessment: a UK perspective. *Journal of Cleaner Production*, 8(2), 127–132. [https://doi.org/10.1016/S0959-6526\(99\)00317-0](https://doi.org/10.1016/S0959-6526(99)00317-0).
- Singh, A. P., Chakrabarti, S., Kumar, S., & Singh, A. (2017). Assessment of air quality in Haora River basin using fuzzy multiple-attribute decision making techniques. *Environmental Monitoring and Assessment*, 189(8), 373. <https://doi.org/10.1007/s10661-017-6075-3>.
- Tu, M. (2016). *The comprehensive assessment research on ecological environment impact of road construction in southern forest region based on GIS*. Fujian Agriculture and Forestry University.
- Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: an overview of applications. *European Journal of Operational Research*, 169(1), 1–29. <https://doi.org/10.1016/j.ejor.2004.04.028>.
- Wang, W. Assessment of social environment impact of the highway construction based on the gray matter-element of information entropy model. In 2009 International Conference on Energy and Environment Technology, 16-18 Oct. 2009 2009 (Vol. 3, pp. 310-313). <https://doi.org/10.1109/ICEET.2009.540>.
- Wang, Z., & Chen, J. (2010). Influence assessment of forest highway's ecological environment based on fuzzy comprehensive evaluation method. *Forest Engineering*, 26(3), 46–48.
- Wang, X., Zhao, C., Yang, Z., Zhao, X., Xing, T., & Wang, Y. (2019). Evaluating rainstorm hazard prevention and mitigation capability in mountainous ecological scenic areas: a case study of the Qinling Mountains, China. *Human and Ecological Risk Assessment: An International Journal*, 1–20. <https://doi.org/10.1080/10807039.2019.1574207>.
- Xia, P., Wang, K., Li, N., & Wu, D. (2011). An improvement of weight in analytic hierarchy process. *Chinese Journal of Health Statistics*, 28(2), 151–154 In Chinese.
- Xu, X. (2006). *The environment impact comprehensive assessment of highway projects in Yunnan Province*. Nanjing Forestry University(In Chinese).
- Xu, L., Li, X., & Xiang, Q. (2010). Positive analysis of social impact assessment of expressway—taking Tumu-Jiaoniwan Section of Beijing-Huashaoying Expressway for instance. *Transportation Research*, 21, 147–152 In Chinese.
- Zhang, Y., & Yang, Q. (2016). Research on mobile Internet security situation assessment based on fuzzy analytic hierarchy process. *Computer Engineering and Applications*, 52(24), 107–111 In Chinese.
- Zhang, X., Xiong, X., Dai, H., Fan, Z., & Chen, K. (2012). Study on fuzzy AHP comprehensive evaluation of the landscape ecology system in highway. In 2012 International conference on Fuzzy Theory and Its Applications (iFUZZY2012), 16-18 Nov. 2012 (pp. 379-383). <https://doi.org/10.1109/iFUZZY.2012.6409735>.

- Zhang, G., Shao, J., Wang, J., Ni, J., & Xie, D. (2015). Spatial and temporal variations of agricultural non-point source pollution in the three gorges reservoir area of Chongqing. *Journal of Natural Resources*, 7, 133–145 In Chinese.
- Zhang, X. Y., Huang, S. F., Yang, S. J., Tu, R. F., & Jin, L. H. (2020). Safety assessment in road construction work system based on group AHP-PCA. *Mathematical Problems in Engineering*, 2020. <https://doi.org/10.1155/2020/6210569>.
- Zhou, S. (2011). Study on distribution center location based on group AHP and fuzzy evaluation. FuZhou University (In Chinese).

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