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Research on Tunnel Engineering in Karst Region by Analyzing with Grey Fuzzy Comprehensive Evaluation

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Abstract: The southwest of China is karst region and in this kind of region, the geotechnical stratum's structure is very complex, so it is very difficult to build the tunnel in the region, as the engineering experience in such long-distance karst is lack. The author introduced fuzzy theory and grey fuzzy theory respectively, list the impact factors of the negative effects of groundwater environment in tunnel project to make subordinate fuzzy function. The objective of this study is to ensure whether the risk in tunnel construction in karst can be evaluated and reduced by using grey fuzzy method. Based on MATLAB Software Platform, the grey fuzzy comprehensive evaluation of tunneling engineering has been realized by combination of fuzzy theory, Analytic Hierarchy Process (AHP) method and the gray correlation analysis method relying on the tunneling of Dian-Ling highway in TongLuo Mountain. The conclusion shows that the preliminary comprehensive evaluation is scientific and efficient in the application for tunneling engineering and grey fuzzy method is more reliable than fuzzy method in karst field.

Key words: Tunneling, karst, AHP, grey fuzzy comprehensive evaluation

INTRODUCTION

Fuzzy mathematics, researching and processing the phenomenon of the "fuzziness" of mathematics with mathematical methods, was first proposed by American expert Professor (Zadeh, 1965). Although, it has been only a few dozens of years, there have been abundant research results on the theory and application of fuzzy logic and fuzzy mathematic has achieved fruitful results (Qi, 1995; Sivanandam *et al.*, 2006).

Grey system theory, which was developed by Chinese expert Professor Deng Julong (Deng, 1982), considers the environment of the research as a system (Zhang and Lu, 2008), including large numbers of white information, black information (unclear) and grey information (partly clear and partly not).

In the actual evaluation work, we have to evaluate things influenced by many factors and those being evaluated are often subject to many uncertainties. Sometimes the fuzzy problem has not enough information, so if fuzzy property and grey action both exist in a research, the impact of them should all be taken into consideration when the comprehensive judgment is carried on (Long *et al.*, 2012). This article evaluated the

impact factors of the negative effects of groundwater environment in tunnel project (Huang *et al.*, 2010). As a system, highway tunnel is affected by many factors on its structural behavior and many influential factors are uncertain with some insufficient information, which are really difficult to quantitatively express the degree how much these uncertain factors affect the structural behavior of the entire tunnel when using classical mathematical methods or traditional comprehensive judgment theory (Kang *et al.*, 2008; Qing, 2009; Liu, 2011). Therefore fuzzy method (Fan *et al.*, 2012) and grey theory are added to the traditional theory to build grey fuzzy comprehensive rating.

CHARACTERISTICS OF KARST

Karst is formed by a variety of geological phenomena that water soluble rocks do comprehensive geological action mainly about dissolution. China karst distribution is quite extensive. Even if talking about the carbonate rocks which are exposed on the surface, the area has already reached 2,030,000 km². Not to mention those are covered and buried underground with the total karst area of 3,630,000 km², occupying more than 1/3 of the land area (Kang *et al.*, 2008; Huang *et al.*, 2010).

The development of tunnel karst is complex which has no regularity, but it also has intrinsic characteristics. According to shape and size, filling characteristics and properties, water inflow in Karst and its dynamic variation features, Karst can be classified as karren, solution groove, Clint, funnel, sinkholes, caves, underground river, shaft; karst valley, natural bridges and karst depressions, etc. (Liu, 2011).

The specificity of the Karst mechanism determines the complex environment of engineering geology, geohydrology, material resources and natural ecology in Karst regions (Zhu and Song, 2011; He *et al.*, 2012).

FUZZY AHP EVALUATION STEPS

Generally, we need the following steps: Determining the evaluation factors, determining evaluation grade set, establishing evaluation matrix, determining the weight vector, fuzzy synthesis and finally making a decision (Zhou *et al.*, 2011; Kreng and Wu, 2007; Tseng *et al.*, 2009).

Determine the evaluation factors: To evaluate an object, we should make it clear which are characterization factors. According to the purpose of the evaluation, main factors which reflect the evaluated object can be filtered out. With the corresponding index measurement, we can get the set of evaluation factors.

Supposing that the number of the main facts which reflects evaluation object is m , respectively expressed by $u_1, u_2, u_3, \dots, u_m$. The evaluation factors set can be formed which is denoted as $U = \{u_1, u_2, u_3, \dots, u_m\}$.

Determine the evaluation grade set: For each factor, we can determine some classes. If the level is classified to n , respectively expressed by $v_1, v_2, v_3, \dots, v_n$, then the evaluation rating is written to be $V = \{v_1, v_2, v_3, \dots, v_n\}$. In this study, the evaluation grade is $V = \{\text{very weak I, weak II, medium III, strong IV, very strong V}\}$.

For each fact u_i ($i = 1, 2, \dots, m$) in the set of evaluation factors, we analyzed its degree of membership r_{ij} to evaluation grade v_j ($j = 1, 2, \dots, n$) and to obtain the single factor evaluation result of the i th factor: $r_i = (r_{i1}, r_{i2}, \dots, r_{in})$, usually, $r_{ij} > 0$:

$$\sum_{j=1}^n r_{ij} = 1$$

Establish the evaluation matrix: For m factors, after the single factor evaluation, we defined the r_i as i th line, to form a fuzzy matrix R which including m factors and n evaluation grades (Zimmermann, 2001):

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \dots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

Determine the weight vector: Usually, evaluation factors reflected are not equally important with each other, so it is necessary to give the factors corresponding weights according to their degree of contribution. According to the process of human intervention in the weight determination, hierarchical analysis method is often used to determine the weight among factors.

Note the weight of fact u_i as w_i , then the weight vector of the factors set U can be expressed as:

$$W = (w_1, w_2, \dots, w_m), w_i > 0 \text{ and } \sum w_i = 1$$

Fuzzy synthesis: On the basis of fuzzy matrix R and the weight vector W having been identified, integrating weighting vector W and the matrix R , we can obtain the membership degree how much that the evaluated object is belonging to evaluation grade from the overall perspective.

Note vector of the results of fuzzy comprehensive evaluation as $S = \{s_1, s_2, \dots, s_n\}$, according to the narrative, S is made up of fuzzy matrix R and the weight vector of W by fuzzy operation, using fuzzy operator representation:

$$S = W \oplus R$$

Among them, $\oplus$ is a fuzzy operator symbol. Commonly used operators are as follow: Weighted average operator, the multiplication operator, bounded operator.

Make a decision: Through observation, we can get the results of fuzzy comprehensive evaluation in term of vector $S = \{s_1, s_2, \dots, s_n\}$. s_j is the degree that how much the evaluated objects are belonging to the evaluation grades. The grade v_j corresponding to the largest s_j suggests that the grade is best suited for that evaluated object and the grade can be used as the evaluation result.

ANALYSE OF ENGINEERING EXAMPLES USING FUZZY METHOD

Project overview: The Dian-lin highway is an expressway that connects Lingshui County in Sichuan province to Dianjiang of Chongqing City and is located approximately 5.8 km from the southeast of the Linshui County, Guang'an City of Sichuan Province. The Dian-lin highway is the main part of national planning "nine vertical and

Table 1: Value of indices for highway quality evaluation

Target layer	Criteria layer	Index layer	Quantitative results
W the ground-water negative effect (A) of a tunnel project	Natural geography (B1)	C11 Multi-year average rainfall (mm)	1215.5
		C12 Multi-year average evaporation (mm)	959.6
		C13 Surface catchment area (km ²)	38.4
		C14 Coefficient of precipitation infiltration	Infiltration coefficient 0.55, occupies 44%; 0.20 occupies 32%; 0.054 occupies 24%
		C15 Relationship between tunnel and topography	About 40% is parallel valleys obliquely downward type, 60% of the other types
		C16 Surface reservoirs, lakes scale (m ³)	300000
		C17 Scale of surface rivers (m ³ sec ⁻¹)	0.3
	Geological and hydrological (B2)	C21 Outcrop area ratio of soluble rock (%)	44
		C22 Strata rich water	Weak: 62.37%, Middle: 30.14%, Strong: 7.5%
		C23 Head pressure (Mpa)	1
		C24 Fold development status	The folds developed by fissure
		C25 The degree of development of broken band	General
		C26 Formation lithology	Accounts for 35% of fine sandstone, limestone and other soluble rock category accounted for 44%
		C27 Zonation	Level of circulation band strong
	Tunnel engineering (B3)	C31 Tunnel length (km)	5.2
		C32 Excavation of cross-sectional area (m ²)	185
		C33 Construction methods	The bench method accounted for 20%, full-face method accounted for 80%
		C34 Tunnel depth (m)	100-300m and <100 m each account for about 50%
		C35 Technology aiming to halt water	Approximately 80% of the composite lining waterproof and about 20% plus a pre-grouting

Table 2: Comprehensive weight of each indicator

Index	C11	C12	C13	C14	C15	C16	C17
Weight	0.0535	0.0251	0.0387	0.0386	0.0539	0.0419	0.0419
Index	C21	C22	C23	C24	C25	C26	C27
Weight	0.0679	0.0705	0.0393	0.0617	0.0834	0.0781	0.0681
Index	C31	C32	C33	C34	C35		
Weight	0.0554	0.0362	0.0477	0.0445	0.0538		

eighteen horizontal" national trunk road highway network, of which the length is 35.8 km, with complex geological conditions, difficult construction and high technical content. Tongluo Mountain Tunnel is the second largest long tunnel in the road, with a total length of 5197 km and is one of the high-speed critical control projects. The tunnel has complex geological conditions and a lot of adverse geological part, including 1500 m karst easy gushing water segment. The tunnel construction began in 2005 and opened to traffic in 2008. This study relies on Tunnel Tongluo mountain of Dian-lin Highway to carry out the study of the engineering case (Kang *et al.*, 2008; Liu, 2011; Zhu and Song, 2011).

Index quantity: Indicators quantity takes the negative effect (A) of a tunnel project groundwater for the target layer, Natural geography (B1), Geology and hydrology (B2) and the Tunnel Engineering Technology (B3) for criteria layers, in which B1 is divided into seven indicator layers (C11-C17), B2 is divided into 7 index layers (C21-C27) and B3 is divided into five indicator layers (C31-C35). The whole specific indicators quantity is as shown in Table 1 (Fan *et al.*, 2012).

Weights determination: This study complies with engineering experience of 10 renowned experts from University of the Western Cape, South Africa, the Ministry of Railways First Survey and Design Institute of

Southwest Jiaotong University units and gets comprehensive weight of each indicator, which are shown in Table 2 (Fan *et al.*, 2012).

Fuzzy relationship matrix establishment: To apply the method of above membership determination to calculation and establish the following fuzzy relation matrix, which are shown in Table 3 (Fan *et al.*, 2012).

Comprehensive evaluation results: Then, fuzzy comprehensive evaluation method can be applied and quantitatively to calculate the groundwater environment negative effect of Tongluo mountain tunnel.

To take natural and geographical factors (B1) set as example and calculate the judge results as follows:

$$B_1 = C_1 \oplus R_1 = (0.1823, 0.0857, 0.1317, 0.1314, 0.1835, 0.1427, 0.1427)$$

$$= \oplus \begin{pmatrix} 0.000 & 0.000 & 0.211 & 0.789 & 0.000 \\ 0.865 & 0.135 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.720 & 0.280 & 0.000 \\ 0.240 & 0.053 & 0.267 & 0.110 & 0.330 \\ 0.600 & 0.000 & 0.400 & 0.000 & 0.000 \\ 0.000 & 0.505 & 0.495 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 & 0.000 & 0.000 \end{pmatrix}$$

$$= (0.2158, 0.2332, 0.3124, 0.1952, 0.0434)$$

Similarly, it can be calculated:

Table 3: Fuzzy relationship matrix

Evaluation index	Evaluation level	Very weak I	Weaker II	Middle III	Stronger IV	Very strong V
Natural geography (B1)	C11 Multi-year average rainfall (mm)	0.000	0.000	0.211	0.789	0.000
	C12 Multi-year average evaporation (mm)	0.865	0.135	0.000	0.000	0.000
	C13 Surface catchment area (km ²)	0.000	0.000	0.720	0.280	0.000
	C14 Coefficient of precipitation infiltration	0.240	0.053	0.267	0.110	0.330
	C15 Relationship between tunnel and topography	0.600	0.000	0.400	0.000	0.000
	C16 Surface reservoirs, lakes scale (m ²)	0.000	0.505	0.495	0.000	0.000
	C17 Scale of surface rivers (m ³ sec ⁻¹)	0.000	1.000	0.000	0.000	0.000
Geology and hydrology (B2)	C21 Outcrop area ratio of soluble rock (%)	0.000	0.800	0.200	0.000	0.000
	C22 Strata rich water	0.624	0.000	0.301	0.000	0.075
	C23 Head pressure (Mpa)	0.000	0.800	0.200	0.000	0.000
	C24 Fold development status	0.000	0.000	0.000	1.000	0.000
	C25 The degree of development of broken band	0.000	0.000	1.000	0.000	0.000
	C26 Formation lithology	0.210	0.350	0.000	0.000	0.440
	C27 Zonation	0.000	0.000	0.450	0.550	0.000
Tunnel engineering (B3)	C31 Tunnel length (km)	0.000	0.289	0.711	0.000	0.000
	C32 Excavation of cross-sectional area (m ²)	0.000	0.000	1.000	0.000	0.000
	C33 Construction methods	0.000	0.000	0.000	0.200	0.800
	C34 Tunnel depth (m)	0.500	0.500	0.000	0.000	0.000
	C35 technology aiming to halt water	0.200	0.000	0.800	0.000	0.000

$$B_2 = (0.1287, 0.2412, 0.3342, 0.2114, 0.0845)$$

$$B_3 = (0.1389, 0.1610, 0.4995, 0.0401, 0.1605)$$

Based on the first grade evaluation results of the criterion layer indexes, second grade evaluation can be carried out according to the criterion layer indexes, so as to obtain the comprehensive evaluation.

Considering tunnel engineering factors (B3), then:
 $W_1 = (0.2935, 0.4689, 0.2377)$:

$$R = \begin{bmatrix} 0.2158 & 0.2332 & 0.3124 & 0.1952 & 0.0434 \\ 0.1287 & 0.2412 & 0.3342 & 0.2114 & 0.0845 \\ 0.1389 & 0.1610 & 0.4995 & 0.0401 & 0.1605 \end{bmatrix}$$

$$S_1 = W_1 \oplus R = (0.2935, 0.4689, 0.2377) \oplus \begin{bmatrix} 0.2158 & 0.2332 & 0.3124 & 0.1952 & 0.0434 \\ 0.1287 & 0.2412 & 0.3342 & 0.2114 & 0.0845 \\ 0.1389 & 0.1610 & 0.4995 & 0.0401 & 0.1605 \end{bmatrix}$$

$$= (0.1567, 0.2198, 0.3671, 0.1659, 0.0905)$$

If the tunnel engineering factors (B3) is not taken into consideration, then:

$$W_2 = \left(\frac{0.2935}{0.2935 + 0.4689}, \frac{0.4689}{0.2935 + 0.4689} \right) = (0.3850, 0.6150)$$

$$R = \begin{bmatrix} 0.2158 & 0.2332 & 0.3124 & 0.1952 & 0.0434 \\ 0.1287 & 0.2412 & 0.3342 & 0.2114 & 0.0845 \end{bmatrix}$$

$$S_2 = W_2 \oplus R = (0.3850, 0.6150) \oplus \begin{bmatrix} 0.2158 & 0.2332 & 0.3124 & 0.1952 & 0.0434 \\ 0.1287 & 0.2412 & 0.3342 & 0.2114 & 0.0845 \end{bmatrix}$$

$$= (0.1622, 0.2381, 0.3258, 0.2052, 0.0687)$$

Combining the calculation results of S1 and S2, it can be known that negative effects of the groundwater environment after the completion of the tunnel project

Tongluo mountain is mainly III level (medium), followed by grade II (weak) and a comprehensive assessment of the results is medium weak.

ANALYSIS OF SAME EXAMPLES USING GREY FUZZY METHOD

Evaluation system of the karst belongs to grey fuzzy system with several indexes, so the result will be more objective and credible by using grey fuzzy system comprehensive evaluation. Considering that whether the karst information is enough can't be described by specific value, the degree can be divided to be {very enough, enough, medium, poor, very poor}, respectively to grey value {0~0.2, 0.2~0.4, 0.4~0.6, 0.6~0.8, 0.8~1.0}. Combining grey theory and fuzzy logic, referencing the process of the model building of fuzzy math and giving grey value to each index, the grey fuzzy system can be achieved (Xu and Zhang, 2001; Qiu, 2004).

Establish factors set of hierarchical evaluation: Table 1.

Determine the degree: The weight of the index and the property are determined by several professional experts based on their engineering experience, so the grey degree of the weight is tentatively set to be 0; the grey degree of the evaluation is set by the rater according to the actual situation, here it being set 0.1 for convenience.

Establish the weight set of evaluation factors: To express the weight of the evaluation factors, a weight set should be built, in which the weight is determined by using the expert scoring, the extreme value statistics method and the calculation of the factors weight based on confidence method (Bu and Zhang, 2002):

$$\bar{C} = [(c_1, v_1)(c_2, v_2) \dots (c_n, v_n)]$$

where, c_i is the fuzzy part of C , v_i is the grey part of C and:

$$\sum_{i=1}^n c_i = 1$$

The definition of:

$$\bar{W}$$

and:

$$\bar{S}$$

mentioned after is similar to:

$$\bar{C}$$

To take natural and geographical factors (B1) set as example, establish the matrix of weight as follows:

$$\bar{C}_1 = [(0.1823, 0)(0.0857, 0)(0.1317, 0)(0.1314, 0)(0.1835, 0)(0.1427, 0)]$$

Determine the matrix of weight and evaluation:
According to the degree of membership of the element to be evaluated and the corresponding grey degree based on whether the information is enough, the evaluation matrix:

$$\bar{R}$$

can be established:

$$\bar{R} = \begin{bmatrix} (a_1, b_1) & \dots & (a_1, b_n) \\ \vdots & \ddots & \vdots \\ (a_n, b_1) & \dots & (a_n, b_n) \end{bmatrix}$$

where, α_n is the degree of membership and b_n is the grey degree.

To take B1 set as example, establish the matrix of evaluation as follows:

$$\bar{R}_1 = \begin{bmatrix} (0,1) & (0,1) & (0.211,1) & (0.789,0.1) & (0.000,1) \\ (0.865,0.1) & (0.135,1) & (0,1) & (0,1) & (0,1) \\ (0,1) & (0,1) & (0.72,0.1) & (0.28,1) & (0,1) \\ (0.24,1) & (0.053,1) & (0.267,1) & (0.11,1) & (0.33,0.1) \\ (0.6,0.1) & (0,1) & (0.4,1) & (0,1) & (0,1) \\ (0,1) & (0.505,0.1) & (0.495,1) & (0,1) & (0,1) \\ (0,1) & (1,0.1) & (0,1) & (0,1) & (0,1) \end{bmatrix}$$

Comprehensive evaluation: To take B1 set as example, calculate the judge results as follows:

$$\begin{aligned} \bar{B}_1 &= \bar{C}_1 \oplus \bar{R}_1 \\ &= [(0.1823, 0)(0.0857, 0)(0.1317, 0)(0.1314, 0)(0.1835, 0)(0.1427, 0)(0.1427, 0)] \\ &\quad \circ \begin{bmatrix} (0,1) & (0,1) & (0.211,1) & (0.789,0.1) & (0.000,1) \\ (0.865,0.1) & (0.135,1) & (0,1) & (0,1) & (0,1) \\ (0,1) & (0,1) & (0.72,0.1) & (0.28,1) & (0,1) \\ (0.24,1) & (0.053,1) & (0.267,1) & (0.11,1) & (0.33,0.1) \\ (0.6,0.1) & (0,1) & (0.4,1) & (0,1) & (0,1) \\ (0,1) & (0.505,0.1) & (0.495,1) & (0,1) & (0,1) \\ (0,1) & (1,0.1) & (0,1) & (0,1) & (0,1) \end{bmatrix} \\ &= [(0.216, 0.01)(0.233, 0.01)(0.313, 0.1)(0.195, 0.1)(0.043, 0.1)] \end{aligned}$$

Similarly, it can be calculated:

$$\bar{B}_2 = [(0.129, 0.1)(0.241, 0.01)(0.334, 0.1)(0.211, 0.01)(0.085, 0.1)]$$

$$\bar{B}_3 = [(0.139, 1)(0.161, 0.1)(0.499, 0.001)(0.040, 1)(0.161, 0.1)]$$

Based on the first grade evaluation results of the criterion layer indexes, second grade evaluation can be carried out according to the criterion layer indexes, so as to obtain the fuzzy comprehensive evaluation as follow:

$$\begin{aligned} \bar{R} &= \begin{bmatrix} \bar{B}_1 \\ \bar{B}_2 \\ \bar{B}_3 \end{bmatrix} \\ &= \begin{bmatrix} (0.216, 0.01) & (0.233, 0.01) & (0.313, 0.1) & (0.195, 0.1) & (0.043, 0.1) \\ (0.129, 0.1) & (0.241, 0.01) & (0.334, 0.1) & (0.211, 0.01) & (0.085, 0.1) \\ (0.139, 1) & (0.161, 0.1) & (0.499, 0.001) & (0.040, 1) & (0.161, 0.1) \end{bmatrix} \end{aligned}$$

Considering tunnel engineering factors (B3), then:

$$\begin{aligned} \bar{W} &= [(0.2935, 0)(0.4689, 0)(0.2377, 0)] \\ \bar{S} &= \bar{W} \circ \bar{R} \\ &= [(0.2935, 0)(0.4689, 0)(0.2377, 0)] \\ &\quad \circ \begin{bmatrix} (0.216, 0.01) & (0.233, 0.01) & (0.313, 0.1) & (0.195, 0.1) & (0.043, 0.1) \\ (0.129, 0.1) & (0.241, 0.01) & (0.334, 0.1) & (0.211, 0.01) & (0.085, 0.1) \\ (0.139, 1) & (0.161, 0.1) & (0.499, 0.001) & (0.040, 1) & (0.161, 0.1) \end{bmatrix} \\ &= [(0.157, 10^{-3}) (0.220, 10^{-3}) (0.367, 10^{-3}) (0.166, 10^{-4}) (0.09, 10^{-3})] \end{aligned}$$

RESULTS

According to the final calculated result, based on the principle of the maximum membership degree and minimum gray, the assessment of grade is III (medium) and the

corresponding grey degree is 0.00001 which means the result is very reliable.

DISCUSSION

For S1 and S2, it is found that when not considering the tunnel engineering factor, compared with that considering the tunnel engineering factor, error of Grade I, II and III is less than 11%, error of Grade IV and V is less than 24%. The results show that before the tunnel construction in such areas, according to the natural geographical and geological and hydrological objective factors, preliminary comprehensive assessment of negative effects of groundwater on the tunnel project in advance to ensure the security and stability of the tunnel project is scientific (Chen, 2009).

By using fuzzy method, the coefficient of safety is similar to that of more safety, so the level of risk can approximately be achieved. But if grey fuzzy method is used, the evaluation of the project can be realized more accurately in the principle of membership degree to be maximum and grey degree of point to be minimum. The grey degree of the point helps the rater do decision more reliably (Wen, 2008).

CONCLUSION

This study introduced fuzzy and grey fuzzy method respectively, relying on Tongluo Mountain Tunnel of Dian-lin Highway and Xulingguan Tunnel of Naqin Highway and studied the real example. Grey fuzzy membership was carried out for the affecting factors of negative effects of groundwater environment on the tunnel project and comprehensively evaluation and analysis were based on MATLAB software.

By contrast, it is found that before the tunnel construction in such areas, according to the natural geographical and geological and hydrological objective factors, preliminary grey comprehensive assessment of negative effects of groundwater on the tunnel project in advance to ensure the security and stability of the tunnel project is scientific and efficiency.

Currently, most of the membership functions are determined by experience of experts. With increasing engineering experience, membership tends to be more and more precise and the grey fuzzy control will also be more and more accurate.

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REFERENCES

- Bu, G.Z. and Y.W. Zhang, 2002. Grey fuzzy comprehensive evaluation based on the theory of grey fuzzy relation. *Syst. Eng. Theory Pract.*, 4: 141-143.
- Chen, Q.M., 2009. Model and application based on grey fuzzy comprehensive judgment. *J. Hefei Univ. (Nat. Sci.)*, 19: 5-7.
- Deng, J.L., 1982. The control problem of grey systems. *Syst. Control Lett.*, 1: 288-294.
- Fan, Z.Q., X.B. Xiong, X.B. Zhang, H.F. Dai and K. Chen, 2012. Fuzzy comprehensive evaluation based on environmental effect of karst tunnel engineering. *Proceedings of the International Conference on Fuzzy Theory and its Applications*, November 16-18, 2012, Taichung, pp: 388-393.
- He, Z.M., H.Y. Fu and Y.Q. Qin, 2012. Classification of water environment around highway in Karst area with two-stage fuzzy synthetic judgment method with changing weight value. *J. Cent. South Univ. (Sci. Technol.)*, 43: 702-708.
- Huang, H.W., L. Che and Q.F. Hu, 2010. *Tunnel and Underground Engineering Life Cycle Risk Management*. Science Press, China.
- Kang, H.R., Q.G. Luo and J.M. Ling, 2008. *Road Construction Theory and Practice of Karst Area*. Communications Press, China.
- Kreng, V.B. and C.Y. Wu, 2007. Evaluation of knowledge portal development tools using a fuzzy AHP approach: The case of Taiwanese stone industry. *Eur. J. Oper. Res.*, 176: 1795-1810.
- Liu, J., 2011. Study on evaluation system of the negative effects Groundwater environment in Karst tunnel. Ph.D. Thesis, Southwest Jiaotong University, China.
- Long, C., C. Zhang, J. Zhang and Y. Liu, 2012. Assessment on vegetation restoration by soil spray seeding technique on road verge slopes of expressway with triangular fuzzy information. *J. Convergence Inform. Technol.*, 7: 324-330.
- Qi, W., 1995. *Practical Fuzzy Mathematics*. Scientific and Technical Documentation Press, China.
- Qing, S.H., 2009. *Southwest Railway Engineering Geological Research and Practice*. China Railway Publishing House, China.
- Qiu, X.R., 2004. Grey fuzzy synthetic assessment for stability of Karst collapse. *Hydrogeol. Eng. Geol.*, 31: 58-61.
- Sivanandam, S.N., S. Sumathi and S.N. Deepa, 2006. *Introduction to Fuzzy Logic using MATLAB*. 1st Edn., Springer-Verlag, New York, ISBN-10: 3540357807, Pages: 444.

- Tseng, M.L., Y.H. Lin and A.S.F. Chiu, 2009. Fuzzy AHP-based study of cleaner production implementation in Taiwan PWB manufacturer. *J. Cleaner Prod.*, 17: 1249-1256.
- Wen, K.L., 2008. A Matlab toolbox for grey clustering and fuzzy comprehensive evaluation. *Adv. Eng. Software*, 39: 137-145.
- Xu, W. and Q. Zhang, 2001. An algorithm of meta-synthesis based on the grey theory and fuzzy mathematics. *Syst. Eng. Theory Pract.*, 21: 114-119.
- Zadeh, L.A., 1965. Fuzzy sets. *Inform. Control*, 8: 338-353.
- Zhang, X. and Y. Lu, 2008. Grey fuzzy comprehensive evaluation based on correlation degree. *Math. Pract. Theory*, 38: 156-160.
- Zhou, H.L., Y.L. Jiang and X. Wan, 2011. Evolving fuzzy neural network for highway subsurface condition evaluation using ground penetrating radar. *Adv. Inform. Sci. Serv. Sci.*, 3: 176-182.
- Zhu, Y. and Y. Song, 2011. *Tunnel Engineering*. China Railway Publishing House, China.
- Zimmermann, H.J., 2001. *Fuzzy Set Theory and Its Applications*. 4th Edn., Kluwer Academic Publishers, New York, Pages: 514.