RESEARCH ARTICLE

Application of Fuzzy analytic hierarchy process in vulnerability assessment of debris flow control project

Ziqiang Liu[1], Bo Xiang[1], Yunyong He[2], Bing Li[1], Haibo Zhou[1]

[1]Sichuan Provincial Department of Transportation Highway Planning ,Survey ,Design and Research Institute, chengdu,610041, China

[2]School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, Sichuan, China

Abstract: The paper firstly introduced distribution and adaptability of the debris flow control work in Sichuan.And then it evaluate vulnerability of the Interception Dam according to development and distribution characteristics of debris flow channel, and scope and purpose of engineering measures. On the basis of generation characteristics of debris flow, systematically analyzed the dam location, its condition, characteristics of debris flow, rainfall and earthquake, the overall five first-level factors and the corresponding eight second-level factors, formed a vulnerability assessment system of the Interception Dam project and evaluated the vulnerability by using analytic hierarchy process and fuzzy comprehensive evaluation method to control project, the result showed that the vulnerability of the control project is low, among them, very low vulnerability has 5, low vulnerability has 18, moderate vulnerability has 4. The result shows that the overall operation of the control project is good, with strong protection. Research results provide certain guiding significance for similar engineering vulnerability assessment area.

Keywords: Debris flow; Control project; Engineering vulnerability; Fuzzy analytical hierarchy process

Citation: Ziqiang Liu, Bo Xiang, Yunyong He, Bing Li and Haibo Zhou, 2022. Application of Fuzzy analytic hierarchy process in vulnerability assessment of debris flow control project. *Journal of Sustainable Urbanization, Planning and Progress,* 6(1): 35-42. http://doi.org/10.26789/JSUPP.2022.01.005

1. Introduction

China is a mountainous country, with 2/3 of total land areas are mountainous regions and plateaus. Besides,there are intense neo-tectonic movements, complexgeological conditions and frequent earthquakesin China.Therefore, debris flow disasters are very seriously destructive in China[1].

Before the project construction, a large debris flow broke out on August 14th, 2010 , pushing out of the total volume of solid substance source up to 0.5*104m3, in which about 40*104m3 source ran into the Min River and blocked off the River [2]. The debris flow caused up lifting of the river water level, and rapidly submergedjust-built new district in Yingxiu Townand buried 400m of 213 National Road highway.It also buried Yingxiu-Wenchuan (Sichuan) Expressway Subgrade (in the construction) and a plurality of bride piers, causing 17 people missing and serious economic loss.The debris flow disaster drew high attention of the central government. Sichuan Provincial Government, Ministry of Water Resources, Ministry of Communications, and Ministry of Land and Resources actively deal with the debris flow, and carried out project exploration, design, construction, finally completedthe debris flow treatment project in May, 2011. It has been more than three years, and the engineering withstands most of verification.

There are several frequent applied debris flow vulnerability assessment methods, which are Analytic Hierarchy Process (AHP), The common way is the organic combination of Fuzzy-AHP. The way is to establish the evaluation model of the Analysis hierarchy process and Fuzzy comprehensive evaluation (Fuzzy-AHP) and realize the semi-quantitative and be easy to obtain of vulnerability assessment index, reduce investigation cost, reflect the fuzziness of the evaluation factors and evaluation process, be more practical than the experts scoring method in general and avoid subjective affection. The method is theoretically desirable and be widely verification on practical using [3].

Fuzzy-AHP comprehensive evaluation method for the single debris flow vulnerability assessment, mostly be used before control engineering implementation, and there are many examples prove the practicability and feasibility of this method[3]. But for the vulnerability assessment of the control engineering after running a period of time is very few people involved in research. In this paper, the Analytic Hierarchy Process (AHP) method combined with the Fuzzy Comprehensive Method was adopted to establish vulnerability assessment index and evaluated the vulnerability of the control engineering.

2. Engineering measurement of the targeted area

Building debris flow control engineering is to reduce the intensity of debris flows, preventing surrounding objects from harms and damages, and ultimately transform the debris flow into sand flow to the river [4].

On the basis of existing construction report of the debris flow in the research area, the service life of control project is 50 years [5]. The layout of the project is shown in Figure 1.The upstream is slope stabilization and source immobilization engineering.The middle streamis debris flow interception. The downstream is drainagechannel engineering. Slope stabilization and source immobilization engineering project aims to stabilize the source, and to prevent formation of material sources, with the main subprojects of Landslide Dams, Check Dams and Foot Walls.Debris flow interception aims to prevent the discharged materials from upstream, at the same time, to stabilize surrounding source, with the main subprojects of Grid Dam, etc.Drainage channel engineering is to discharge the sand mixed with water from the middle stream smoothly into the Min River. The main subprojects for drainagechannel engineering are drainage channels, etc.

2.1 The upstream slop stabilization and source immobilization engineering

The upper stream of target area develops three major tributaries, which are, from left to right respectively, Gan Xi Pu Tributary, Da Shui Gou Tributary and Xin Dian Zi Gou Tributary. The project layout of the three tributaries is shown as Figure 1.

(1) Gan Xi Pu Tributary is with poor engineering geological condition for dangerous steeps, large slope, and abundant material sources. The project is mainly to control channel source and prevent landslide. And the same time, it controls right-bank slumping and disperses the source, so as to relieve the congestion on the downstream channel. The distribution of the project is shown as following photos: two Landslide Dams (Photo 1), two groups of Check Dams (Photo 2) and a section of supporting Foot Walls.

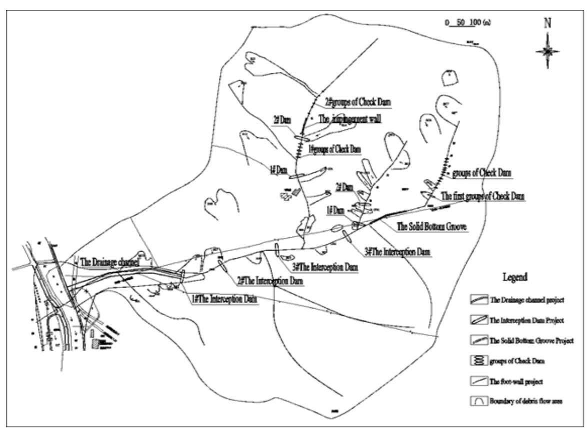

Figure 1: The surface chart of distribution of the control project

(2) Da Shui Gou: the tributaries with rich material source, the upstream of sub-tributaries with dangerous

steeps, rapid flow velocity, relatively poor geological conditions. The down stream of the sub-tributary is with relatively slow flow velocity, exposed bedrock at the gully bottom, therefore, the engineering geological condition is relatively good. The control project is distributed as two Landslide Dams on the down stream (Photo 3), with the objective of slowing the flow and relieving the congestion.

(3) The upper section of Xin Dian Zi Gou Tributary is with dangerous steeps, rapid flow velocity, and abundant material sources, mainly avalanche deposits. The slope of middle section is smaller, and the main source is the channel deposits. The downstream is with loose deposits, and deformation of right bank slump. The project is distributed as groups of Check Dams at the middle section (Photo 4) and Enhanced Bottom Groove at the lower section.

2.2 The middle stream debris flow interception

No.1 dam and No. 2 dam are at the middle and down section of main channel (Photo 5, 6).Due to its large capacity, hey are set to retain debris flow material from the upstream, at the same time, stabilize surrounding slumping source, and excrete harmless sand flow or debris flows. No.3 dam and No. 4dam are located at the entrance of downstream of Gan Xi Pu Gou and Da Shui Gou (Figure 1).The role of No.3 dam is to control blocking, while No.4 dam is to slow the flow and alleviate the blocking.

Photo 1 Gan Xi Pu, No. 1 Dam

Photo 2 Gan Xi Pu, groups of Check Dam

Photo 3 Dashui Gou, No.1 Landslide Dam

Photo 4 Xin Dian zi Gou groups of Check Dam

Photo 5 Middle stream, No.1 dam

Photo 6 Middle stream, No.2 dam

2.3 The downstream drainage channel engineering

The downstream drainage channel project connects upstream with No.1 dam, down stream with G213 national highway, and Du-wen Expressway with the Min River. And ultimately, it achieves that sandy flows or turbulent debris flows pass through No.1 Grille dam and flow smoothly into the Minjiang, without blocking or causing startup of new debris flow source in surrounding area. Drainage channel is with 805mlength, 19-35mwidth, and 2.0-2.5m height (Photo 7).

Photo 7 The downstream, drainage channel

3. The system of vulnerability assessment index

According to actual condition of the project, the research too kvulnerability assessment of the interception dam as an example.

3.1 Selection of factors

Fuzzy-AHP refers to the combination of Fuzzy Comprehensive Analysis Method and Analytic Hierarchy Process Method. Based onAnalytic Hierarchy Process, which is applied for calculation of Weight Vector, and Fuzzy Comprehensive Method, which is a relative membership degree theory, the research established Fuzzy-AHP vulnerability evaluation model for the project[6].

In the target area, because vulnerability of the Interception Dam reflects different understanding of some potential hazards due to different engineering geological environment and its own structure. The study selected the dam location factorU1, the Interception Dam self condition factor U2, characteristics of debris flow factorU3, rainfall factor U4 and earthquake factor U5 as first-level evaluation factors (index) (Table 1).

In the column U1, basic indicators, C1 and C2, mainly consider impact of geological condition of the Interception Dam and condition of debris flow on space of debris flow. In the column U2, basic indicators, C3 and C4, mainly reveal the effect of engineering specifications and strength on vulnerability. In the column U3,basic indicators, C5 and C6 mainly consider impacts of debris flow's scale and frequency on vulnerability.In the column U4, basic indicator, C7 mainly analyzes the influence of rainfall on engineering vulnerability. The basic indicator of U5, C8, is to study the effect of earthquakes on engineering vulnerability.

Table 1 Value scope of the interception project vulnerability assessment index

Index Types		Index Grades				
Category	Basic indicators	Extremely high vulnerability	High vulnerability	moderate vulnerability	Low vulnerability	Extremely low vulnerability
Location（U1）	Geological condition of the dam（C1）	Complex geological condition, bad geological phenomenon usually happen, relatively poorer bearing capacity of the dam foundation.	Complex geological condition, bad geological phenomenon often happen, poor bearing capacity of the dam foundation.	Average geological condition, bad geological phenomenon occasionally happen, average bearing capacity of the dam foundation.	Good geological condition, no need of enforcement，good bearing capacity of the dam foundation	Better geological conditions，better bearing capacity of the dam foundation.
	Relative location of the dam and the debris flow（C2）	Located in the flowing zone, richer material source, steeper slope, most destructive to the Interception Dam.	Located in the flowing zone, rich material sources, steep slope, more destructive to the Interception Dam.	Located in the flowing zone，partial material sources，destructive to some extend.	Located on the upstream，less material sources, less destructive.	Located in forming zone，covered with vegetation, lest material sources
Condition of the dam（U2）	Height(m)（C3）	<2	2~4	4~5	5~7	>7
	Building materials（C4）	brick	stone	iron	concrete	Reinforced concrete
Features of the debris flow（U3）	Scale(10^4m^3)（C5）	＞100	10~100	10~5	5~1	＜1
	Frequency/ times/year（C6）	＞1	1~0.1	0.1~0.01	0.01~0.001	＜0.001
Rainfall（U4）	Annual average rainfall (mm)（C7）	＞1000	800-1000	600-800	100-600	＜100
Earthquakes（U5）	Seismic intensity（C8）	＞9	8~9	7~8	5~7	＜5

3.2 Construction of assessment index system

According to the assessment index, the study built the hierarchical structure [7], which is divided into three levels: the goal layer E (the ultimate vulnerability index), the category index layer Ui (i.e. the first-level index), and the basic index layer Ci (i.e. The second-level index) (Figure 2).

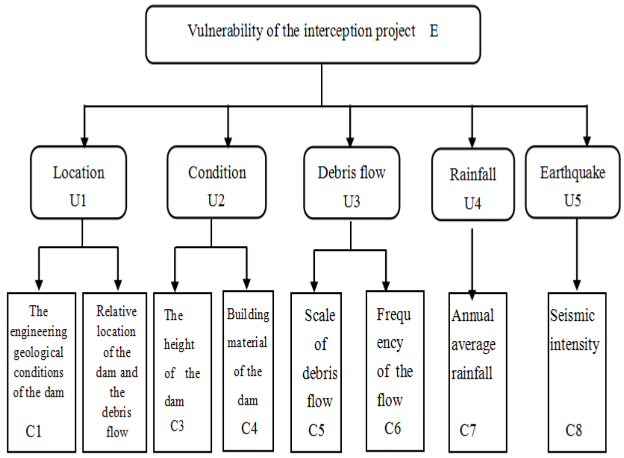

Figure 2 The vulnerability assessment system of the Interception Project

3.3 Determination of Weight Vector

The study applied analytic hierarchy process (AHP) to determine Weight Vector of assessment indexes. The characteristic of Analytic Hierarchy Process is that it combines qualitative and quantitative analysis, so as to quantitatively measure decision maker's experience and judgment. The study used 1-9 scale method (Table 2) to mark for the assessment factors, and established judgment matrix of the index (Table 3)[8].When consistency of the judgment matrix is reasonable, Weight Vector will be get as Table 4.

Table 2 Scale and implication in factors comparison

Scale value	implications
1	Implicate that two factors compare, and both value the same
3	Implicate that two factors compare, the former is more important than the latter
5	Implicate that two factors compare, the former is more important than the latter
7	Implicate that two factors compare, the former is much more important than the latter
9	Implicate that two factors compare, the former is extremely most important than the latter
2,4,6,8	Implicate the average value of the above judgment.
inverse	Considering value of factor i and factor j as a_{ij}， then the ratio of actor i and factor j can be $a_{ji}=1/a_{ij}$

Table 3 First-level index judgment matrix

Indexes	U_1	U_2	U_3	U_4	U_5
U_1	1	3	1/5	1/3	1/4
U_2	1/3	1	1/6	1/4	1/5
U_3	5	6	1	3	2

U_4	3	4	1/3	1	1/2
U_5	4	5	1/2	2	1

To check the consistency of the judgment matrix, it accords with the principle of consistency. So we can get the eigenvectors associated with λ_{max}.And then after normalization, the result is that W= (0.1227, 0.0436, 0.3494, 0.2079, 0.2764), namely, the index Weight Vector.

Similarly, we can get the Weight Vector of the second-level index (Table 4), so the Weight Vector of each index is shown as follows after calculation:

Table 4 Weight Vector of each index

Level (U) / Level (C)	U_1	U_2	U_3	U_4	U_5
	0.1227	0.0436	0.3494	0.2079	0.2764
C_1	0.8333	0	0	0	0
C_2	0.1667	0	0	0	0
C_3	0	0.3333	0	0	0
C_4	0	0.6667	0	0	0
C_5	0	0	0.6	0	0
C_6	0	0	0.4	0	0
C_7	0	0	0	0.2079	0
C_8	0	0	0	0	0.2764

4. Fuzzy Comprehensive Method determines the grade of vulnerability

4.1 Establishment of the assessment set

Assessment set is a collection of various evaluation results of the object, i.e.:

$V=\{V_1,V_2, \dots ,V_i\}$

In the formula, V_i implicates possible evaluation results of each factor. Judging from Fuzzy Comprehensive Evaluation Method, the best evaluation results are selected from the collection. According to the actual situation, the study choose 5 levels of results, i.e.:

V={extremely high vulnerability, high vulnerability, moderate vulnerability, low vulnerability, extremely low vulnerability}

4.2 Establishment of membership function

Because the factors of control engineering vulnerability include quantitative factors and qualitative factors, the membership function is also divided into quantitative and qualitative membership function [9].

I. Quantitative membership function

According to principle of determining membership function, it is suitable for ridge-type distribution function.

$$f_1=\begin{cases}0 & x\le a_1\\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_2-a_1}\left(x-\frac{a_2+a_1}{2}\right) & a_1<x<a_2\\ 1 & x\ge a_2\end{cases}$$

$$f_2=\begin{cases}0 & x\le a_0\\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_1-a_0}\left(x-\frac{a_1+a_0}{2}\right) & a_0<x\le a_1\\ 1 & a_1<x\le a_2\\ \frac{1}{2}-\frac{1}{2}\sin\frac{\pi}{a_3-a_2}\left(x-\frac{a_3+a_2}{2}\right) & a_2<x\le a_3\\ 0 & x>a_3\end{cases}$$

$$f_3=\begin{cases}0 & x\le a_1\\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_2-a_1}\left(x-\frac{a_2+a_1}{2}\right) & a_1<x\le a_2\\ 1 & a_2<x\le a_3\\ \frac{1}{2}-\frac{1}{2}\sin\frac{\pi}{a_4-a_3}\left(x-\frac{a_4+a_3}{2}\right) & a_3<x\le a_4\\ 0 & x>a_4\end{cases}$$

$$f_4=\begin{cases}0 & x\le a_0\\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_1-a_0}\left(x-\frac{a_1+a_0}{2}\right) & a_0<x\le a_1\\ 1 & a_1<x\le a_2\\ \frac{1}{2}-\frac{1}{2}\sin\frac{\pi}{a_3-a_2}\left(x-\frac{a_3+a_2}{2}\right) & a_2<x\le a_3\\ 0 & x>a_3\end{cases}$$

$$f_5=\begin{cases}1 & x\le a_1\\ \frac{1}{2}-\frac{1}{2}\sin\frac{\pi}{a_2-a_1}\left(x-\frac{a_2+a_1}{2}\right) & a_1<x<a_2\\ 0 & x\ge a_2\end{cases}$$

Ⅱ Qualitative membership function

Because qualitative indexes could not be numerically distinguished from each other, it can not refer to quantitative function. For the qualitative index, it can be judged by the grading methods, that is, quantify these indicators firstly. Qualitative indexes can be divided into bad, poor, moderate, good and excellent, with the given value, 0.9, 0.7, 0.5, 0.3 and 0.1. Therefore, according to the principle of determining membership function, here ladder function is applied:

$$u_{\mathrm{I}}=\begin{cases}0 & x\le 0.75\\ 10x-7.5 & 0.75<x\le 0.85\\ 1 & x>0.85\end{cases}$$

$$u_{\mathrm{II}}=\begin{cases}0 & x\le 0.55\\ 10x-5.5 & 0.55<x\le 0.65\\ 1 & 0.65<x\le 0.75\\ 8.5-10x & 0.75<x\le 0.85\\ 0 & x>0.85\end{cases}$$

$$u_{\mathrm{III}}=\begin{cases}0 & x\le 0.35\\ 10x-3.5 & 0.35<x\le 0.45\\ 1 & 0.45<x\le 0.55\\ 6.5-10x & 0.55<x\le 0.65\\ 0 & x>0.65\end{cases}$$

$$u_{\mathrm{IV}}=\begin{cases}0 & x\le 0.15\\ 10x-1.5 & 0.15<x\le 0.25\\ 1 & 0.25<x\le 0.35\\ 4.5-10x & 0.35<x\le 0.45\\ 0 & x>0.45\end{cases}$$

$$u_{\mathrm{V}}=\begin{cases}1 & x\le 0.15\\ 2.5\text{-}10x & 0.15<x\le 0.25\\ 0 & x>0.25\end{cases}$$

In all these formulas, χ represents actual value of index, a_l represents limits of evaluation index level.

4.3 Determination of initial value of evaluation index

Take No. 1 Railings Dam on the middle reach as an example. The dam is located in the flowing area, with small amount of source involved, 20m designed height, 2m depth of overflow port , 18meffective dam height , C25 concrete structure. In this section, channel width is 62m.Channel average longitudinal gradientis140 ‰.The dam foundation in the channel is mainly accumulation of debris flow source, which is structure-loosed, being composed of gravelly soil mixed with gravel and sand. Size of stone commonly is 0.3-0.6m, and some individual is bigger than 1.5m.The underlying bedrock is moderate-weakly weathered diorite, with high rock strength. The debris flow scale is considered as 8.14 in debris flow evaluation index, including Gan Xi Pu Gou sourcing out the quantity of 21.4×104m3, Da Shui Gou6.6×104m3, and Xin Dian Zi Gou 5.2×104m3. The upper section of the main channel accounted for 4.0×104m3, the middle section 40.8×104m3, and the lower section 2.5×104m3. In addition, due to occurrence frequency of debris flow on the basis of the actual situation in recent years, the study took 1 times / year. The average annual rainfall is 1253.1m. Earthquake intensity in this area is Ⅷ degree. Based on above data, initial index value is shown as Table 5.

Table 5 Initial value of vulnerability assessment for No. 1.Railings

index / project	Location of the dam		Condition of the dam		Debris flow		rainfall	earthquake
	C_1	C_2	C_3	C_7	C_5	C_6	C_7	C_8
Middle. No. 1	0.44	0.14	20	8	40.8	1	1253.1	8

4.4 Determination of the membership degree

(1) Determination membership of secondary factors

With reference to the above qualitative membership function, as well as the basic conditions of No. 1 Railings Dam on the middle reach and A section of downstream drainage channel, it can be drawn out the initial value of the two projects and membership degree of two-level index (as shown in Table 6).

Table 6 Membership degree of second-level index for No. 1 Railing Dam on the middle reach

Primary index	Secondary index	Index fuzzy membership degree
Location of the dam	C_1	(0, 0, 0.9, 0.1, 0)
	C_2	(0, 0, 0, 0, 1)
The self-condition of the dam	C_3	(0, 0, 0, 0, 1)
	C_4	(0, 0, 0, 05, 0.5)
Debris flow	C_5	(0, 1, 0, 0, 0)
	C_6	(1, 0, 0, 0, 0)
Rainfall	C_7	(1, 0, 0, 0, 0)
Earthquake	C_8	(0, 0, 1, 0, 0)

(2) Determination of primary fuzzy vector

Two-level evaluation index membership degree has been determined as illustrated as above. The study constructed a two-level evaluation fuzzy matrix, and then calculated fuzzy vector of each first-level index by using a fuzzy calculation formula.The results are shown in table 7.

Table 7 The first-level fuzzy calculation results of the control project

Project type	Primary index	Secondary index	weighting	Index fuzzy membership degree	First-level fuzzy vector
The interception dam	Location	C_1	0.8333	(0, 0, 0.9, 0.1, 0)	(0, 0, 0.75, 0.0833, 0.1677)
		C_2	0.1667	(0, 0, 0, 0, 1)	
	Condition of the dam	C_3	0.3333	(0, 0, 0, 0, 1)	(0, 0, 0, 0.3333, 0.6667)
		C_4	0.6667	(0, 0, 0, 0.5, 0.5)	
	Debris flow	C_5	0.6	(0, 1, 0, 0, 0)	(0.4, 0.6, 0, 0, 0)
		C_6	0.4	(1, 0, 0, 0, 0)	
	rainfall	C_7	0.2079	(1, 0, 0, 0, 0)	(0.2079, 0, 0, 0, 0)
	earthquake	C_8	0.2764	(0, 0, 1, 0, 0)	(0, 0, 0.2764, 0, 0)

4.5 Results of vulnerability assessment of the control project

(1) Classification of index

According to hazard classification of the debris flow done by [10] and other scholars, and Bradford law [11], the study classify the vulnerability of the control project into five grades, between [0,1], with 0.2 as the tolerances. Finally vulnerability classification can be shown as Table 8.

Table 8 Vulnerability classification of the control project

Vulnerability level	Extremely high	high	moderate	low	Extremely low
Vulnerability index	0.8 ~ 1.0	0.6 ~ 0.8	0.4 ~ 0.6	0.2 ~ 0.4	0 ~ 0.2

(2) Vulnerability assessment index

According to above first-level fuzzy vector, the fuzzy comprehensive evaluation vector can be obtained as shown in Table 9.

Table 9 Results of fuzzy comprehensive evaluation vector

Project type	First-level index	weighting	First-level fuzzy vector	fuzzy comprehensive evaluation vector
The interception dam	location	0.1227	(0, 0, 0.75, 0.0833, 0.1677)	(0.183, 0.2096, 0.1684, 0.0248, 0.0496)
	Conditions	0.0436	(0, 0, 0, 0.3333, 0.6667)	
	Debris flow	0.3494	(0.4, 0.6, 0, 0, 0)	
	rainfall	0.2079	(0.2079, 0, 0, 0, 0)	
	earthquake	0.2764	(0, 0, 0.2764, 0, 0)	

Table 9 shows the vectors of fuzzy comprehensive evaluation of No. 1.Railings Dam on the middle reachas0.183, 0.2096, 0.1684, 0.0248, and 0.0496. According to maximum principle of membership vector, it is drawn out that vulnerability index of No. 1.Railings Dam on the middle reach is 0.2096. Judging from Table 8, No.1.Railings Dam on the middle reach is with low vulnerability.

Based on this method, vulnerability index can be obtained for other projects. And finally the study obtained level of vulnerability of each project (Table 10).

Table 10 Level of vulnerability of each project

Project type	Fuzzy results	Vulnerability index	Vulnerability level
No.2 dam, main channel middle reaches	(0.2014, 0.1173, 0.0395, 0.2974 , 0.1381)	0.2974	low
No.3 dam, main channel middle reaches	(0. 1199, 0.025, 0.1943, 0.2472, 0.2016)	0.2472	low
No.4 dam, main channel middle reaches	(0.1027, 0.0425, 0.1689, 0.2261, 0.201)	0.4261	moderate
Gan Xi Pu No. 1 dam	(0.1056, 0.2102, 0.2375, 0.1061 , 0.2187)	0.2375	low
Gan Xi Pu No. 1 Check Dam	(0.3151, 0.2172, 0.1305, 0.2914 , 0.1985)	0.3151	low
Gan Xi Pu No. 2 Check Dam	(0.2416, 0.2102, 0.2005, 0.1991 , 0.1357)	0.2416	low
Gan Xi Pu No. 3 Check Dam	(0.4192, 0.2901, 0.3304, 0.2041 , 0.3015)	0.4192	moderate
Gan Xi Pu No. 2 dam	(0.3015, 0.2172, 0.1315, 0.2092 , 0.1346)	0.3015	low
Gan Xi Pu No. 4 Check Dam	(0.2191, 0.2193, 0.246, 0.2032 , 0.3365)	0.3365	low
Gan Xi Pu No.5 Check Dam	(0.3792, 0.4101, 0.2373, 0.2095 , 0.1985)	0.4101	moderate
Gan Xi Pu No. 6 Check Dam	(0.5091, 0.3761, 0.3159, 0.4197 , 0.3381)	0.5091	moderate
Gan Xi Pu No. 7 Check Dam	(0.2183, 0.2139, 0.3304, 0.3192 , 0.2352)	0.3304	low
Da Shui Gou No.1 dam	(0.1086, 0.1147, 0.1841, 0.1074 , 0.1749)	0.1841	extremely low
Da Shui Gou No.1 dam	(0.0994, 0.2029, 0.2001, 0.1017 , 0.2061)	0.2061	low
Xin Dian Zi Gou No.1 Check Dam	(0.1646, 0.2392, 0.3725, 0.2191 , 0.3085)	0.3725	low
Xin Dian Zi Gou No.2 Check Dam	(0.1969, 0.2109, 0.1865, 0.1493 , 0.2381)	0.2381	low
Xin Dian Zi Gou No.3 Check Dam	(0.2112, 0.2714, 0.1392, 0.2077 , 0.2161)	0.2714	low
Xin Dian Zi Gou No.4 Check Dam	(0.1987, 0.1731, 0.2496, 0.2311 , 0.1639)	0.2496	low
Xin Dian Zi Gou No.5 Check Dam	(0.1961, 0.1329, 0.0703, 0.1544 , 0.1732)	0.1961	extremely low
Xin Dian Zi Gou No.6 Check Dam	(0.2006, 0.2573, 0.1055, 0.2396 , 0.1984)	0.2573	low
Xin Dian Zi Gou No.7 Check Dam	(0.2991, 0.1808, 0.1777, 0.3142 , 0.2013)	0.3142	low
Xin Dian Zi Gou No.8 Check Dam	(0.2577, 0.1635, 0.2375, 0.1455 , 0.3386)	0.3386	low
Drainage canal, Main channel lower reaches B section	(0.1042, 0.0749, 0, 0.1793 , 0.0091)	0.1793	extremely low
Drainage canal, Main channel lower reaches C section	(0.1007, 0.1901, 0.1734, 0.1037 , 0.1315)	0.1734	extremely low
Drainage canal, Main channel lower reaches D section	(0.0493, 0.1442, 0.0075, 0.1016 , 0.1131)	0.1442	extremely low

5. Conclusion

(1) Based on growth characteristics of the debris flow, the whole control project was designed as the upstream slopestabilization and source immobilization engineering, the middle stream debris flow interception, and the downstream drainage channel project.

(2)Based on characteristics of the control project, a vulnerability assessment system has been constructed. The study firstly selected location of the project, condition of project itself, characteristics of debris flow, rainfall, and earthquake, overall 5 factors as first-level indicators, which are specified into 8 secondary-level indexes. Then with the help of the Analytic Hierarchy Process and Fuzzy Comprehensive Method, vulnerability of the dam was classified.

(3) Applying the Analytic Hierarchy Process and Fuzzy Comprehensive Method for vulnerability assessment of control project, the evaluation revealed result as low vulnerability, including five moderate low vulnerability, 18 low vulnerability , 4 moderate vulnerability (Table 10). The results showed that the overall running situation of the project is good with its protective ability.

Acknowledgements

The research is funded by the project of National Natural Science Foundation of China "Research on the mechanism of deformation of granular slope failure" (No.41072228)

References

[1] Wang, J-K. (1996). Debris Flows Prevention Engineering Technology.Peking: China Railway Publishing House.

[2] Zhang, J-S. (2012). Research of vulnerability and risk assessment of debris flows in Wenchuan based on GIS. Chengdu: Chengdu University of Technology Press.

[3] He, Z-H. (2012). The Debris Flow assessment method based on Fuzzy-AHP method and its application. Guangzhou. South China University of Technology Press.

[4] Cui, P. (2009). Advances in debris flow prevention in China.Science of Soil and Water Conservation,7(5): 7-13.

[5] Sichuan Huadi Construction Engineering Limited Company (2010). Report on Targeted area Debris Flow Construction Graph. Chengdu: Sichuan Huadi Construction Engineering Limited Company :41-85.

[6] Jin, Y. (2011). Vulnerability and risk assessment of rainstorm debris flows along Yalu Tsangpo Rver to Jiacha. Chengdu: Chengdu University of Technology Press.

[7] Yang, X-M. & Liang, S-Y. (2008). Application of Fuzzy Analytic Hierarchy Process Method to debris flow dangerous degree assessment.Journal of Geological Hazards and Environment Preservation, 2008, 19(2):73-78.

[8] Xu, L-R., Wang, L. & Su, Z-M. (2010). Assessment of engineering vulnerability of tunnel suffering from debris flow. Rock and Soil Mechanis, 31(7):2153-2157.

[9] Xie, J-J. & Liu, C-P. (2000). Fuzzy Mathematics Method and Application. Wuhan: Huazhong Science and Technology University Press.

[10] Liu, X-L. & Tang, C. (2004). Dangerous Degree ssessment. Peking: Science Press.

[11] Yi, Z-M. (2011). Consideration to the Rationality of Bradford 's Law. Journal of Library and Information Sciences in Agriculture, 23(1):126-129.

[12] Chang, J-E. & Jiang, T-L. (2007). Research on the Weight of Coefficient through Analytic Hierarchy Process. Wuhan: Journal of Wuhan University of Technology (Information and Management