Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 2031907, 12 pages
https://doi.org/10.1155/2022/2031907

Research Article

The Risk Assessment of Debris Flow in the Duba River Watershed Using Intuitionistic Fuzzy Sets: TOPSIS Model

Xin-Bao Gu[1,2] **Li Wang**,[3] **and Qi-Hong Wu**[4]

[1]*School of Civil Engineering, Nanyang Institute of Technology, Nanyang, Henan, China*
[2]*Henan International Joint Laboratory of Dynamics of Impact and Disaster of Engineering Structures, Nanyang, Henan, China*
[3]*Nanyang Institute of Architecture and Design, Nanyang, Henan 47300, China*
[4]*School of Architecture and Civil Engineering, Chengdu University, Chengdu, Sichuan, China*

Correspondence should be addressed to Qi-Hong Wu; 15700679755@139.com

Received 24 February 2022; Revised 27 March 2022; Accepted 6 April 2022; Published 28 April 2022

Academic Editor: Xinyu Xie

The occurrence of debris flow hazards has great destructive effects on the life and property safety of the people. Many factors control its occurrence. The intuitionistic fuzzy sets-TOPSIS model is introduced to assess the risk level of debris flow in the Duba river watershed at first; secondly, the decisive matrix of the intuitionistic fuzzy sets is established, and the index weight coefficients are determined by using the entropy weight method, and then the weighed decisive matrix is obtained. Finally, the degree of membership at different levels is calculated. The risk level corresponding to the maximum degree of membership is regarded as the final assessment level. The conclusions are drawn, estimating that the risk level of debris flow hazards in the Duba river watershed based on the intuitionistic fuzzy sets-TOPSIS model is feasible when its results are compared with the actual investigation and Liu X.L model, and the model not only can reflect the risk level of debris flow hazards accurately, but also further determines the risk ranking of debris flow in four different gullies, so that it can provide a new method and thoughts to estimate the risk level of debris flow hazards in the future.

1. Introduction

With the development of science and technology and the progress of human society, the urbanization is accelerated gradually [2], the human demand for resources is becoming more extensive, and the destruction of environment is obvious increasingly, so the geological hazards occur frequently. In particular, in mountainous areas, the occurrence of debris flow hazards has seriously endangered the life and property safety of the people [3]. So, the risk assessment for debris flow hazards has great significance.

The debris flow hazard is a common geological hazard characterized by high flow rate, significant impact, and wide influential ranges [4]. The investigations on the risk assessment and prevention measurement have been performed by researchers in many countries [5]. In 1976, Dr David J. Varnes in the FBI had assessed the risk level of debris flow, and this information provides the basis for the hazard classification of debris flow in the future [6]. And the judgment of the risk level of the debris flow is suggested by Glade T [7] according to topography, rainfall, and morphological characteristics. Hollingsworth adopts the scoring systems in America in 1981 to establish the risk assessment frame of debris flow [8]. The type and scale of the debris flow are depicted by Eldeen in Switzerland [9] using the method of the zoning map. In China, correlating investigations about the risk level assessment of debris flow have been performed by many researchers [10] during the last 30 years. In 1993, the qualitative assessment model of debris flow was provided by Liu et al. [1]. Chu et al. suggested the fuzzy mathematical method to assess the risk level of debris flow, and lots of uncertainties in the technique are considered [11]. The neural network model for the risk assessment of debris flow was established by Cao et al. in 2014 [12]. Then, the analytic hierarchy process for the risk assessment of single gully is provided by Wang [13]. The fuzzy comprehensive evaluation model in two stages is suggested by Wang [14] to assess the risk level of debris flow; with the development of GIS technology in recent years, it has been widely applied to the risk assessment of debris flow. For example, the investigation on the visualization of morphological characteristics about debris flow is performed by Walsh et al. [15] based on GIS Technology. Besides, the risk level of debris flow hazards in Banshanmen Gully is assessed by Gu et al. [16] based on the entropy weight-normal cloud method. And the risk level of debris flow in Zhouqu is also evaluated by Gu et al. [17] based on Projection Pursuit Classification (PPC) model. The above methods have been applied to determine the risk level of debris flow successfully. Besides, TOPSIS model is applied to analyze the sensibility of debris flow [18, 19], and other methods are also applied [20, 21]; although these above methods improve the development of assessment theory about the debris flow, however, these models still have some shortcomings, such as complex processes and uncertainty.

Relative to the traditional vague mathematical method, the nonmembership function is added in the intuitionistic fuzzy sets [22], so the vague concept can be expressed definitively. And it is characterized as the sufficient usage of original datum, minor information loss, and wide application [23], so it is an efficient multiple attribute decision-making method [24]. A new model is constructed when the intuitionistic fuzzy sets theory is combined with the TOPSIS model. In comparison with the traditional methods, the new model has higher efficiency.

The paper is organized as follows: in Section 2, the study area's engineering overview is first introduced. In Section 3, a new risk assessment method of debris flow hazards is presented based on the Intuitionistic Fuzzy Sets-TOPSIS model. In Section 4, the Intuitionistic Fuzzy Sets-TOPSIS model is established about the debris flow hazards in the Duba River watershed, and the assessment results of the proposed model are discussed. In Section 5, we introduce the discussions and comparative analysis. In section 6, conclusions and future directions are obtained.

2. The Study Area

Duba river is located in the northeast of Beichuan county, Mianyang city, Sichuan Province, China. It belongs to Fujiang river systems, the valley covers throughout the Duba Township and Chenjiaba township, and its specification locations are plotted in Figure 1. The Beichuan county is located at the intersection point of the Sichuan basin and the Tibetan plateau. The summer is hot; the winter is mild and wet; the rainfall is abundant. The mean annual rainfall in the study area is 1399.1 mm, the yearly maximum rainfall is 2340 mm, the minimum yearly rainfall is 619.8 mm, and the maximum daily rainfall is 101 mm. The spatial and temporal distribution of rainfall is highly uneven; the rainfall amounts from July to October account for 73% of the whole years. The rainfall in the study area is characterized as a gradual increase from the northwest to southeast; it is plotted in Figure 2.

The total length of the Duba River is approximate 48 km; the watershed area is 269 km2. The height difference is

Figure 1: The location of survey area.

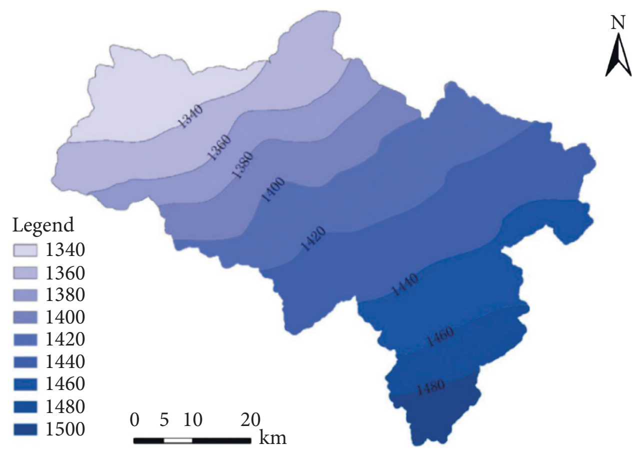

Figure 2: Rainfall contour map.

1704m, the mean longitudinal gradient is 40%0, and the gradient of longitudinal slope gradually becomes gentle from the upstream to downstream. There are many branch ditches in the Duba river basin, such as Yangjia gully, Leijia gully, Qinlin gully, and Yangchangzi gully. The average longitudinal gradient of each gully is 140~200%0. The Duba River spans two types of large geomorphic units. The Guan lingchen Jiaba is selected as the boundary line. The geomorphology at its western side is Zhongshan topography with the Erosional structure. One at its eastern side is Mountain-valley erosion type of low Zhongshan Topography; it is plotted in Figure 3.

The exposed stratum in the Duba river watershed includes the Sinian system light shadow group, Qingping formation of Lower Cambrian, and the quaternary strata. According to the relevant statistics, only in the Yangjia gully, the total sum of loose solid sources arrives at 2191.24 × 104m3, and the dynamic reserves of potential debris flow activity arrive at 675.99 × 104m3. Five large scales of debris flow hazards occurred after the 5.12 earthquake in Wenchuan county, China, especially on 9.24,2008 and 7.9,2013. One-time discharges of debris flow are,

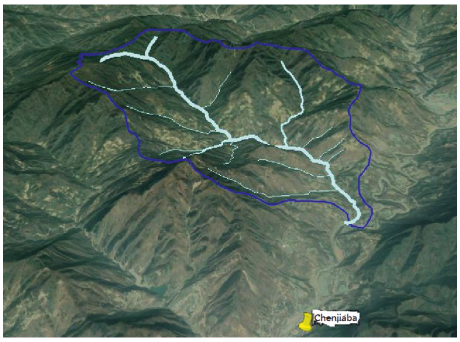

Figure 3: Topographic map.

respectively, 17 × 104m3 and 29 × 104m3. So, the risk assessment of debris flow hazards in the Duba River watershed has great significance to prevent its occurrence in the future.

3. Methodology

3.1. The Establishment of Risk Assessment Frame. Debris flow hazards have threatened the life and property safety of people seriously. Consequently, a new assessment method of debris flow is suggested; its frame figure is plotted in Figure 4.

It can be found in Figure 4 that the assessment indices are determined about the debris flow hazards firstly; secondly, a complete assessment index system is built in the Duba River watershed; thirdly, the parameters of membership and nonmembership degree function are, respectively, calculated, the decisive matrix of the debris flow is constructed, and the weight coefficients based on the entropy method are determined. Then, the weighted decisive matrix is determined; finally, ranking sequences of the degree of membership are selected, and the risk levels of debris flow hazards are judged according to the maximum degree of membership criterion.

3.2. The Determination of Risk Assessment Index about the Debris Flow. The occurrence of debris flow is very complex; many factors should be considered. To ensure the independence and system of the evaluation process, and in combination with the actual investigation, the following nine indices in the paper are selected as the assessment index of debris flow in the Duba River watershed. The assessment indexes include one-time discharge of debris flow (X1), the reserves of loose solid sources (X2), the ratio of silt supply length (X3), the watershed area (X4), the length of the main ditch (X5), the relative height difference in the watershed (X6), the bending coefficient of the main ditch (X7), the mean gradient of the main ditch (X8), and the 24-hour maximum rainfall (X9). These assessment indices are all quantitative ones. The nine assessment indexes are classified into four levels: low risk (I), medium risk (II), high risk (III), and higher risk (IV), as shown in Table 1.

3.3. The Entropy Weight Theory. Its calculative process is expressed as follows:

(1) normalization of different indices: their expression is shown as follows:

$$\mathrm{r}_{ij} = \frac{x_{ij} - x_{i\,\mathrm{min}}}{x_{i\,\mathrm{max}} - x_{i\,\mathrm{min}}}, \tag{1}$$

$$\mathrm{r}_{ij} = \frac{x_{i\mathrm{max}} - x_{ij}}{x_{i\,\mathrm{max}} - x_{i\,\mathrm{min}}}, \tag{2}$$

where x_{ij} is the corresponding magnitude of the jth assessment index in the ith scheme $(i = 1, 2, 3, \ldots, m;\ j = 1, 2, 3, \ldots, n)$.

(2) The determination of index weights.

Based on the normalized index matrix, the index weights can be calculated as follows:

$$\omega_j = \frac{1 - s_j}{n - \sum_{j=1}^{n} s_j}, \tag{3}$$

where $s_j = -k\sum_{i=1}^{n} b_{ij} \ln (b_{ij})$, $b_{ij} = x_{ij}/\sum_{i=1}^{n} x_{ij}$

3.4. The Establishment of Decisive Matrix about the Intuitionistic Fuzzy Sets. The intuitionistic fuzzy sets model originated form the fuzzy sets theory. It is provided by Atanassov [25] at first. In the theory, two scales are applied to define the fuzziness (membership degree and nonmembership degree), and three states (support, opposition, and neutrality) can be described, so it has a wide application prospect.

x is assumed as a nonempty sets, and X is given domain, and an intuitionistic fuzzy set in X can be defined as [2]

$$A = \{\langle x, \mu_A(x), \nu_A(x) | tx \in X\rangle\}, \tag{4}$$

where and represents respectively the membership degree and nonmembership degree of the element $x \in A$ in X; and it should meet with the conditions: $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \le 1, x \in X$ is called degree of hesitation of $x \in A$.

To establish the intuitionistic fuzzy matrix, the corresponding determined parameters about the membership and nonmembership degree can be expressed as

$$\begin{aligned}
\mu_{\mathrm{nk}} &= \exp\left[-\frac{(x_n - c_{\mu k})^2}{2\sigma_{\mu k}^2}\right], \\
\nu_{\mathrm{nk}} &= 1 - \exp\left[-\frac{(x_n - c_{\gamma k})^2}{2\sigma_{\gamma k}^2}\right], \\
\mathrm{c}_{uk} &= c_{\gamma k} = \frac{\underline{S_k} + \overline{S_k}}{2}, \\
\sigma_{\mu\mathrm{k}}^2 &= -\frac{(\overline{S_k} - c_{\mu k})^2}{2\ \ln 1 - \alpha/2}, \\
\sigma_{\gamma\mathrm{k}}^2 &= -\frac{(\overline{S_k} - c_{\gamma k})^2}{2\ \ln(\alpha + 1 - \alpha/2)},
\end{aligned} \tag{5}$$

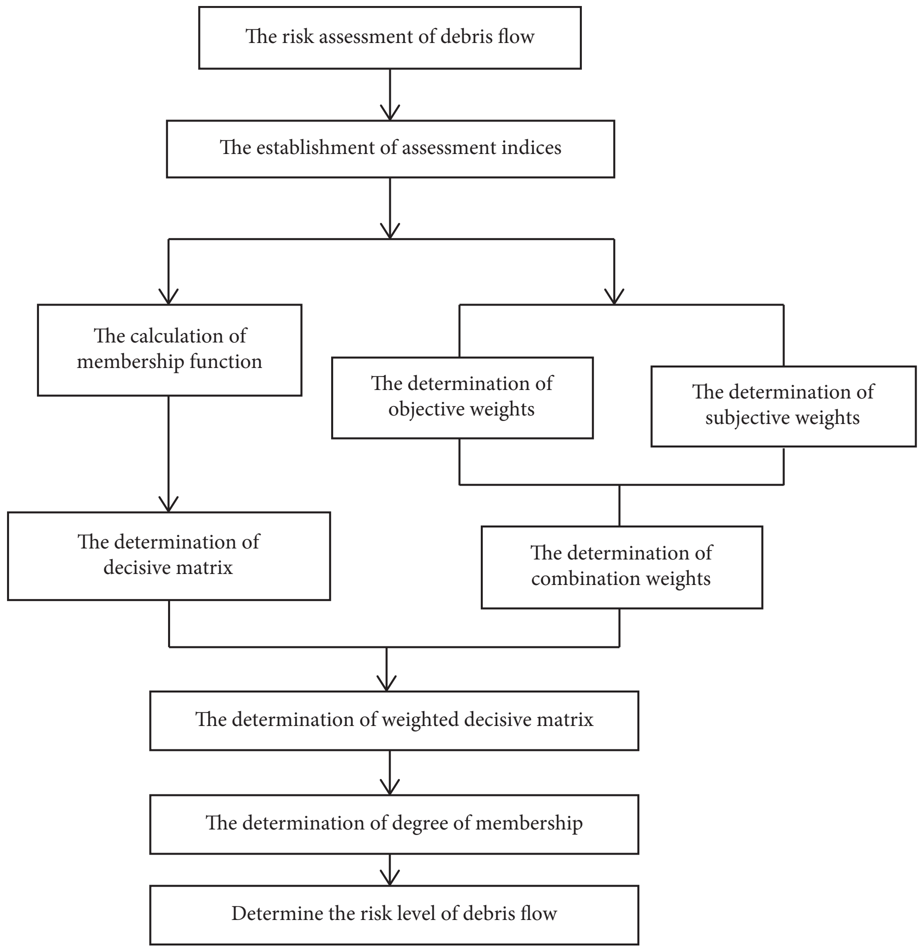

Figure 4: The risk assessment process of debris flow hazards.

Table 1: The classification standard of debris flow hazards.

Assessment index	The risk level classification			
	I	II	III	IV
One-time discharge of debris flow (X_1)	≤1	1~10	10~100	≥100
The reserves of loose solid sources (X_2)	≤10	10~100	100~500	≥500
The ratio of silt supply length (X_3)	≤0.1	0.1~0.3	0.3~0.6	0.6~1
The watershed area (X_4)	≤0.5	0.5~10	10~35	≥35
The length of main ditch (X_5)	≤1	1~5	5~10	≥10
The relative height difference in the watershed (X_6)	≤0.2	0.2~0.7	0.7~1.5	≥1.5
The bending coefficient of main ditch (X_7)	≤1.1	1.1~1.25	1.25~1.40	≥1.40
The mean gradient of the main ditch (X_8)	≤100	100~200	200~350	≥350
The 24-hour maximum rainfall (X_9)	≤25	25~50	50~100	≥100

where $c_{\mu k}$, $c_{\gamma k}$, $\sigma_{\mu k}$, $\sigma_{\gamma k}$ are, respectively, correlate parameters; α is the hesitating degree; it is equal to 0.2 in the paper.

According to the intuitionistic fuzzy number $A_{\text{nk}} = \langle \mu_{nk}, \nu_{nk} \rangle$, the decisive matrix can be obtained as

$$F_P = \begin{bmatrix} (\mu_{11}, \nu_{11}) & (\mu_{12}, \nu_{12}) & \dots & (\mu_{1K}, \nu_{1K}) \\ (\mu_{21}, \nu_{21}) & (\mu_{22}, \nu_{22}) & \dots & (\mu_{2K}, \nu_{2K}) \\ \dots & \dots & \dots & \dots \\ (\mu_{N1}, \nu_{N1}) & (\mu_{N2}, \nu_{N2}) & \dots & (\mu_{NK}, \nu_{NK}) \end{bmatrix}. \quad (6)$$

3.5. Intuitionistic Fuzzy Sets-TOPSIS Model. Its specific procedure is shown as follows:

(1) The assessment index of debris flow is analyzed at first, and classification standards are constructed.

(2) The determination of weight coefficients

The weights of membership degree are $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n)$, its weights of nonmembership degree are $\beta = (\beta_1, \beta_2, \dots, \beta_n)$, and then its combination weights coefficients can be expressed as [2]

$$\omega_{\mathrm{n}} = \langle \chi_{n}, \gamma_{n} \rangle = \langle \min(\alpha_{n}, \beta_{n}), 1 - \max(\alpha_{n}, \beta_{n}) \rangle, \tag{7}$$

where the combination weights represent, respectively, the important and nonimportant degree; it should meet $0 \leq \chi_n + \gamma_{\mathrm{n}} \leq 1$.

(3) According to equations (10) and (11), the weighted decisive matrix is depicted as

$$\overline{F_{\mathrm{P}}} = \omega_{\mathrm{n}} F = \langle \chi_n \mu_{nk}, \gamma_n + \nu_{nk} - \gamma_n \nu_{nk} \rangle_{n\times k}. \tag{8}$$

(4) the determination of plus and negative ideal solution.

They can be expressed as

$$\begin{aligned} B^{+} &= \left[\langle \mu_1^{+}, \nu_1^{+} \rangle, \langle \mu_2^{+}, \nu_2^{+} \rangle, \ldots \langle \mu_{\mathrm{n}}^{+}, \nu_n^{+} \rangle \right], \\ B^{-} &= \left[\langle \mu_1^{-}, \nu_1^{-} \rangle, \langle \mu_2^{-}, \nu_2^{-} \rangle, \ldots \langle \mu_{\mathrm{n}}^{-}, \nu_n^{-} \rangle \right], \end{aligned} \tag{9}$$

where $\mu_{\mathrm{n}}^{+} = \max_{1\leq k\leq n} (\overline{\mu_{nk}})$; $\nu_{\mathrm{n}}^{+} = \max_{1\leq k\leq n} (\overline{\nu_{nk}})$; $\mu_{\mathrm{n}}^{-} = \min_{1\leq k\leq n} (\overline{\mu_{nk}})$; $\nu_{\mathrm{n}}^{-} = \max_{1\leq k\leq n} (\overline{\nu_{nk}})$; $n = 1, 2, \ldots, n$

(5) the determination of Euclidean distance.

The Euclidean distance of plus and negative ideal solutions are calculated as follows:

$$\begin{aligned} D(s_k, B^{+}) &= \sqrt{\frac{1}{2} \sum_{n=1}^{N} \left[(\overline{\mu_{nk}} - \mu_n^{+})^2 + (\overline{\nu_{nk}} - \nu_n^{+})^2 + (\mu_n^{+} + \nu_n^{+} - \overline{\mu_{nk}} - \overline{\nu_{nk}})^2 \right]}, \\ D(s_k, B^{-}) &= \sqrt{\frac{1}{2} \sum_{n=1}^{N} \left[(\overline{\mu_{nk}} - \mu_n^{-})^2 + (\overline{\nu_{nk}} - \nu_{\mathrm{nk}}^{-})^2 + (\mu_n^{-} + \nu_n^{-} - \overline{\mu_{nk}} - \overline{\nu_{nk}})^2 \right]}, \\ \eta_{\mathrm{k}} &= \frac{D^2(s_k, B^{-})}{D^2(s_k, B^{-}) + D^2(s_k, B^{+})}, \end{aligned} \tag{10}$$

where and are respectively the Euclidean distance of plus and negative ideal solutions; η_k is the degree of membership at scheme Sk.

(6) the determination of debris flow hazards level.

When the membership degrees are determined, the maximum membership degree is determined as the assessment levels of debris flow.

4. The Establishment of Risk Assessment Model about Debris Flow

To assess the risk level of debris flow hazards in the Duba River watershed, four gullies are selected as the samples; they all belong to the Duba River watershed. They are, respectively, Yangjia gully, Leijia gully, Qinglin gully, and Yangchangzi gully; their original datum is shown in Table 2 as follows.

According to Table 1, and in combination with E.qs(5)-(9), for Yangjia gully, the parameters of membership and nonmembership function about the intuitionistic fuzzy sets can be shown in Table 3.

To reflect the characters of intuitionistic fuzzy sets, the membership function and nonmembership function are, respectively, plotted in Figures 5 and 6.

Yangjia gully is selected to assess the risk level of debris flow in the paper. According to (1) and (2) (6), and in combination with Figures 5 and 6, the decisive matrix F of intuitionistic fuzzy sets can be expressed as follows:

$$F = \begin{bmatrix} (0,1) & (0,1) & (0.6865, 0.1891) & (0.0036, 0.9564) \\ (0,1) & (0,1) & (0.0392, 0.8356) & (0.9729, 0.0152) \\ (0,1) & (0,1) & (0.1398, 0.6671) & (0.6787, 0.1939) \\ (0,1) & (0, 0.9999) & (0.964, 0.0202) & (0.0068, 0.938) \\ (0,1) & (0.0018, 0.9701) & (0.9223, 0.0441) & (0.0702, 0.7726) \\ (0,1) & (0, 0.9994) & (0.5808, 0.2613) & (0.18, 0.6154) \\ (0.2465, 0.542) & (0.6139, 0.2404) & (0.2332, 0.5598) & (0, 0.9957) \\ (0.1344, 0.6734) & (0.7805, 0.129) & (0.0244, 0.8739) & (0, 0.9997) \\ (0,1) & (0,1) & (0,1) & (0.8327, 0.0952) \end{bmatrix}. \tag{11}$$

Table 2: The original datum about the debris flow in different gullies.

Gully name	X_1 $10^4\,m^3$	X_2 $10^4\,m^3$	X_3 /	X_4 km^2	X_5 km	X_6 km	X_7 /	X_8 ‰	X_9 mm
Yangjia gully	26.17	675.99	0.67	25	8.243	1.408	1.23	124	388.5
Leijia gully	11.15	141.37	0.754	0.8	2.027	0.851	1.038	420	386
Qinglin gully	178.11	455	0.118	23.7	9.944	1.07	1.29	105	392
Yangchangzi gully	13.99	109.7	0.319	5.8	3.746	1.277	1.142	208	396

Based on equation (11), the intuitionistic weights can be calculated as follows, according to the intuitionistic fuzzy number:

$\omega = [\ (0.0812, 0.8567)\ \ (0.1294, 0.8309)\ \ (0.0831, 0.9017)\ \ (0.1423, 0.8367)\ (0.1183, 0.8526)\ \ (0.0666, 0.9112)\ (0.042,\ 0.9309)(0.0909, 0.8977)(0.118, 0.8533)]$ Constituting the expression of matrix F and into equation (12), the weighted intuitionistic fuzzy sets can be expressed as follows:

$$\overline{F} = \omega F = \begin{bmatrix} (0,1) & (0,1) & (0.0557, 0.8838) & (0.0003, 0.9938) \\ (0,1) & (0,1) & (0.0051, 0.9722) & (0.1259, 0.8335) \\ (0,1) & (0,1) & (0.0114, 0.9673) & (0.0564, 0.9208) \\ (0,1) & (0,1) & (0.1372, 0.84) & (0.001, 0.9899) \\ (0,1) & (0.0002, 0.9956) & (0.1091, 0.8625) & (0.0083, 0.9665) \\ (0,1) & (0, 0.9999) & (0.0387, 0.9344) & (0.012, 0.9658) \\ (0.0104, 0.9684) & (0.0258, 0.9475) & (0.0098, 0.9696) & (0, 0.9997) \\ (0.0122, 0.9666) & (0.0709, 0.9109) & (0.0022, 0.9871) & (0,1) \\ (0,1) & (0,1) & (0,1) & (0.0983, 0.8673) \end{bmatrix}. \quad (12)$$

According to the equation (13), the minus and plus ideal solutions of corresponding levels in Yangjia gully can be expressed:

$$\begin{aligned} B^+ &= [\ (0.0122, 0.9666)\ \ (0.0709, 0.9109)\ \ (0.1372, 0.84)\ \ (0.1259, 0.8335)\ ], \\ B^- &= [\ (0,1)\ \ (0,1)\ \ (0,1)\ \ (0,1)\ ]. \end{aligned} \quad (13)$$

According to Eqs (14)-(16), the Euclidean distance of minus and plus ideal solutions for Yangjia gully can be obtained as follows:

$D(t_1, B^+) = 0.0707, D(t_1, B^-) = 0.0412$, $\eta_1 = 0.2537D(t_2, B^+) = 0.2186$, $D(t_2, B^-) = 0.0938$, $\eta_2 = 0.1555D(t_3, B^+) = 0.3279$, $D(t_2, B^-) = 0.2324$, $\eta_3 = 0.3343D(t_4, B^+) = 0.3543$, $D(t_2, B^-) = 0.2099$, $\eta_4 = 0.2598$

It can be found in the above expressions that $\eta_3 > \eta_4 > \eta_1 > \eta_{21}$, based on the maximum distance criterion, and the risk level of debris flow in Yangjia gully is III; this level means that the occurrence of debris flow hazards in Yangjia gully has high risk, and the result is consistent with the one of the actual investigation [26].

Similar to Yangjia gully, the Euclidean distance and degree of membership of minus and plus ideal solutions corresponding to the intuitionistic fuzzy sets of different levels for Leijia gully, Qinglin gully, and Yangchangzi gully are, respectively, shown in Table 4.

It can be found in Table 4 that the risk level of different gullies can be divided into four groups from low to high. The final risk level of debris flow hazards in Yangjia gully, Leijia gully, Qinglin gully, and Yangchangzi gully is III. These conclusions mean that the risk levels of debris flow hazards in the Duba River watershed are high, so the corresponding measures should be adopted to prevent the occurrence of debris flow hazards in the Duba river watershed; for example, the steep landslides should be consolidated. So, the assessment results provide the basis for the prevention of debris flow hazards in the Duba river watershed in the future.

The comparison and analysis of the assessment results in Table 4 show that the results assessed using three methods are completely consistent in different gullies. Its accurate rate arrives at 100% in the text method, and it is the same as Liu X.L method [27]. So, the conclusions are drawn that it is feasible to assess the risk level of debris flow hazards by using

Table 3: The parameters of membership and nonmembership function.

Level index	I	II	III	IV
X_1	$c_{\mu 1} = c_{\gamma 1} = 0.5\sigma_{\mu 1}^2 = 0.1364\sigma_{\gamma 1}^2 = 0.2447$	$c_{\mu 2} = c_{\gamma 2} = 5.5\sigma_{\mu 2}^2 = 11.05\sigma_{\gamma 2}^2 = 19.82$	$c_{\mu 3} = c_{\gamma 3} = 55\sigma_{\mu 3}^2 = 1105\sigma_{\gamma 3}^2 = 1982.1$	$c_{\mu 4} = c_{\gamma 4} = 150\sigma_{\mu 4}^2 = 1364.2\sigma_{\gamma 4}^2 = 2447$
X_2	$c_{\mu 1} = c_{\gamma 1} = 5\sigma_{\mu 1}^2 = 13.64\sigma_{\gamma 1}^2 = 24.47$	$c_{\mu 2} = c_{\gamma 2} = 55\sigma_{\mu 2}^2 = 1105\sigma_{\gamma 2}^2 = 1982.1$	$c_{\mu 3} = c_{\gamma 3} = 300\sigma_{\mu 3}^2 = 21827\sigma_{\gamma 3}^2 = 39152$	$c_{\mu 4} = c_{\gamma 4} = 650\sigma_{\mu 4}^2 = 12278\sigma_{\gamma 4}^2 = 22023$
X_3	$c_{\mu 1} = c_{\gamma 1} = 0.05\sigma_{\mu 1}^2 = 0.0014\sigma_{\gamma 1}^2 = 0.0024$	$c_{\mu 2} = c_{\gamma 2} = 0.2\sigma_{\mu 2}^2 = 0.0055\sigma_{\gamma 2}^2 = 0.0098$	$c_{\mu 3} = c_{\gamma 3} = 0.45\sigma_{\mu 3}^2 = 0.0123\sigma_{\gamma 3}^2 = 0.022$	$c_{\mu 4} = c_{\gamma 4} = 0.8\sigma_{\mu 4}^2 = 0.0218\sigma_{\gamma 4}^2 = 0.0392$
X_4	$c_{\mu 1} = c_{\gamma 1} = 0.25\sigma_{\mu 1}^2 = 0.0341\sigma_{\gamma 1}^2 = 0.0612$	$c_{\mu 2} = c_{\gamma 2} = 5.25\sigma_{\mu 2}^2 = 12.3119\sigma_{\gamma 2}^2 = 22.0843$	$c_{\mu 3} = c_{\gamma 3} = 22.5\sigma_{\mu 3}^2 = 85.2622\sigma_{\gamma 4}^2 = 152.9387$	$c_{\mu 4} = c_{\gamma 4} = 42.5\sigma_{\mu 4}^2 = 30.6944\sigma_{\gamma 4}^2 = 55.0579$
X_5	$c_{\mu 1} = c_{\gamma 1} = 0.5\sigma_{\mu 1}^2 = 0.1364\sigma_{\gamma 1}^2 = 0.2447$	$c_{\mu 2} = c_{\gamma 2} = 3\sigma_{\mu 2}^2 = 2.1827\sigma_{\gamma 2}^2 = 3.9152$	$c_{\mu 3} = c_{\gamma 3} = 7.5\sigma_{\mu 3}^2 = 3.4105\sigma_{\gamma 3}^2 = 6.1175$	$c_{\mu 4} = c_{\gamma 4} = 12.5\sigma_{\mu 4}^2 = 3.4105\sigma_{\gamma 4}^2 = 6.1175$
X_6	$c_{\mu 1} = c_{\gamma 1} = 0.1\sigma_{\mu 1}^2 = 0.0055\sigma_{\gamma 1}^2 = 0.0098$	$c_{\mu 2} = c_{\gamma 2} = 0.45\sigma_{\mu 2}^2 = 0.0341\sigma_{\gamma 2}^2 = 0.0612$	$c_{\mu 3} = c_{\gamma 3} = 1.1\sigma_{\mu 3}^2 = 0.0873\sigma_{\gamma 3}^2 = 0.1566$	$c_{\mu 4} = c_{\gamma 4} = 1.75\sigma_{\mu 4}^2 = 0.0341\sigma_{\gamma 4}^2 = 0.0612$
X_7	$c_{\mu 1} = c_{\gamma 1} = 0.55\sigma_{\mu 1}^2 = 0.1651\sigma_{\gamma 1}^2 = 0.2961$	$c_{\mu 2} = c_{\gamma 2} = 1.175\sigma_{\mu 2}^2 = 0.0031\sigma_{\gamma 2}^2 = 0.0055$	$c_{\mu 3} = c_{\gamma 3} = 1.325\sigma_{\mu 3}^2 = 0.0031\sigma_{\gamma 3}^2 = 0.0055$	$c_{\mu 4} = c_{\gamma 4} = 1.475\sigma_{\mu 4}^2 = 0.0031\sigma_{\gamma 4}^2 = 0.0055$
X_8	$c_{\mu 1} = c_{\gamma 1} = 50\sigma_{\mu 1}^2 = 1364.2\sigma_{\gamma 1}^2 = 2447$	$c_{\mu 2} = c_{\gamma 2} = 150\sigma_{\mu 2}^2 = 1364.2\sigma_{\gamma 2}^2 = 2447$	$c_{\mu 3} = c_{\gamma 3} = 275\sigma_{\mu 3}^2 = 3069.4\sigma_{\gamma 3}^2 = 5505.8$	$c_{\mu 4} = c_{\gamma 4} = 425\sigma_{\mu 4}^2 = 3069.4\sigma_{\gamma 4}^2 = 5505.8$
X_9	$c_{\mu 1} = c_{\gamma 1} = 12.5\sigma_{\mu 1}^2 = 85.2622\sigma_{\gamma 1}^2 = 152.9387$	$c_{\mu 2} = c_{\gamma 2} = 37.5\sigma_{\mu 2}^2 = 85.2622\sigma_{\gamma 2}^2 = 152.9387$	$c_{\mu 3} = c_{\gamma 3} = 75\sigma_{\mu 3}^2 = 341.049\sigma_{\gamma 3}^2 = 611.7547$	$c_{\mu 4} = c_{\gamma 4} = 300\sigma_{\mu 4}^2 = 21827\sigma_{\gamma 4}^2 = 39152$

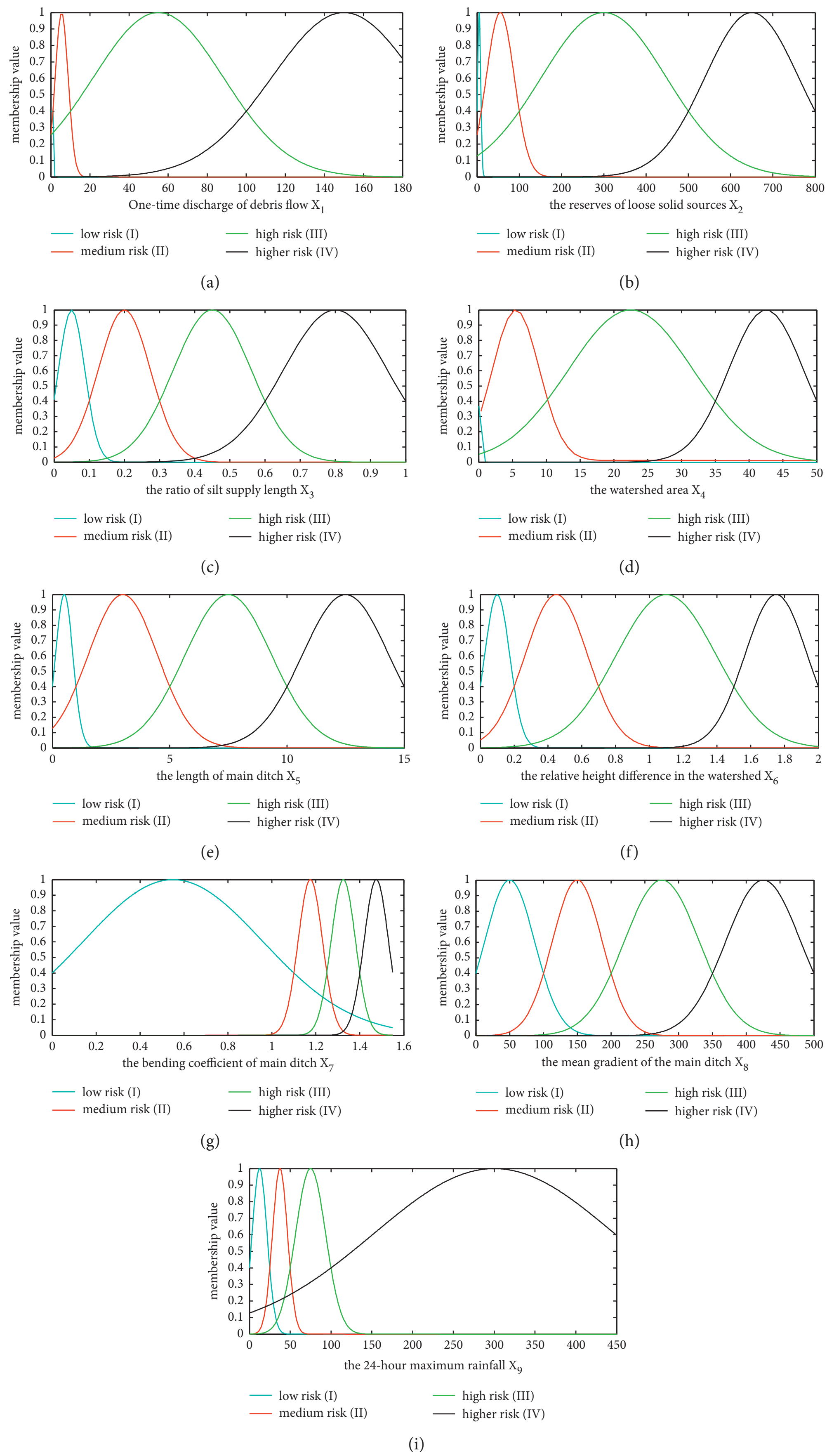

FIGURE 5: The membership function of different intuitionistic fuzzy sets.

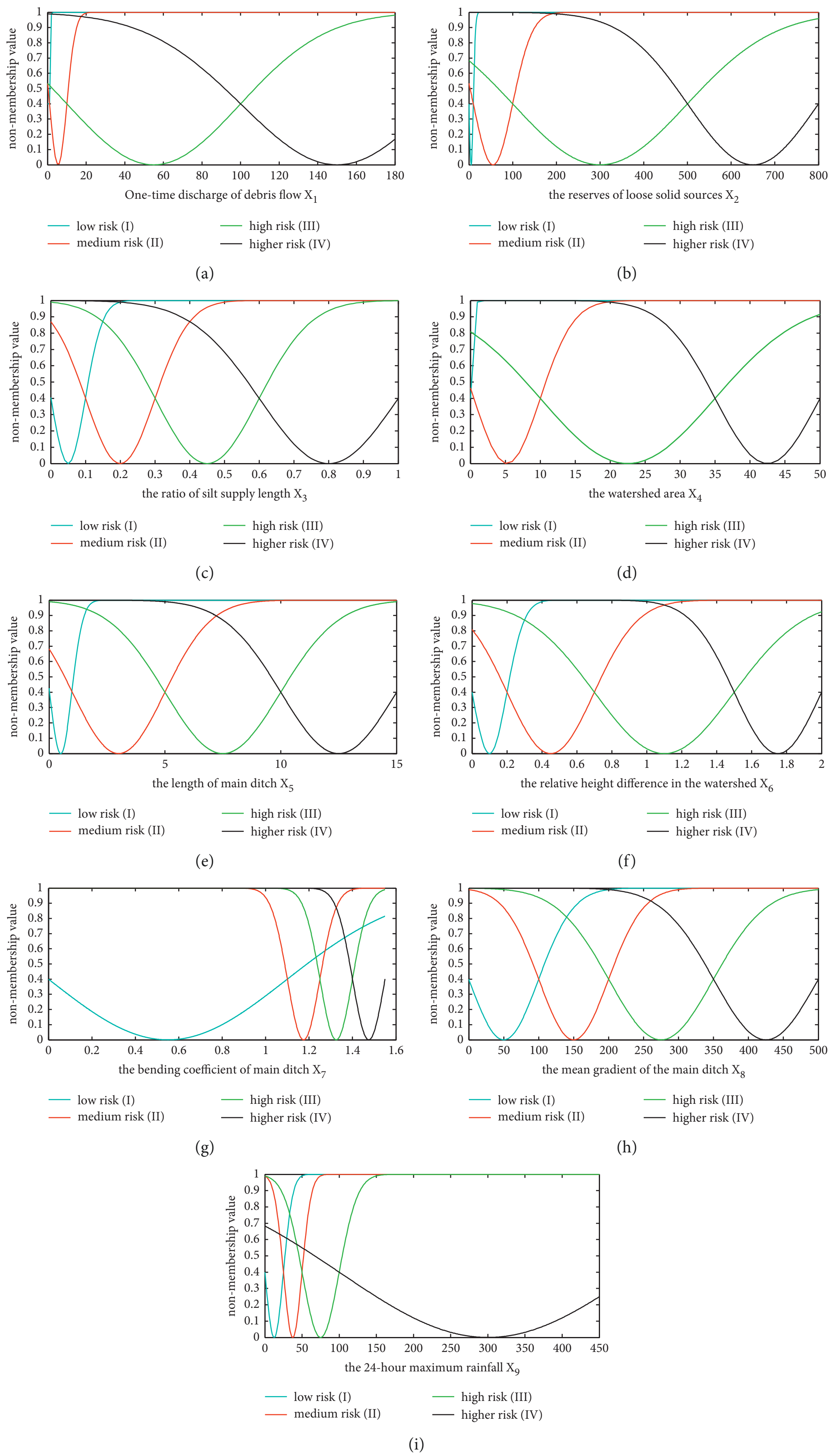

Figure 6: The nonmembership function of different intuitionistic fuzzy sets.

Table 4: The risk assessment of debris flow hazards and comparison.

Gully name	The risk level I	II	III	IV	The text method	Actual investigation	Liu XL Model
Yangjia gully	0.2537	0.1555	0.3343	0.2598	III	III	III
Leijia gully	0.1157	0.2842	0.4323	0.3646	III	III	III
Qinglin gully	0.1773	0.2771	0.3238	0.2101	III	III	III
Yangchangzi gully	0.111	0.2918	0.3559	0.1176	III	III	III

the intuitionistic fuzzy sets-TOPSIS model. And relative to the above methods, the complex prediction model need not be constructed, and high dimensional calculation can be avoided; its calculative process is convenient and straightforward, so the technique has excellent application prospects.

It can also be found in Table 4 that the model achieves accurate results and provides more details about the risk assessment of debris flow hazards. For example, the one-time discharge of debris flow in Qinglin gully is 178.11, which should belong to level IV according to Table 1. In addition, the degree of membership of the other more indices obtained by the TOPSIS model belongs to level III. The risk level probability of debris flow hazards in Qinglin gully at the level III is bigger than the ones of levels I, II, and IV. So, it only belongs to level III and almost impossibly belongs to groups I, II, and IV. The conclusions are consistent with the actual investigation. Furthermore, the risk level of debris flow in Leijia gully is more likely to be level III more than that of Yangjia gully, Qinglin gully, and Yangchangzi gully because the maximum degree of membership in the Leijia gully for level III (0.4323) is higher than that of Yangjia gully (0.3343), Qinglin gully (0.3238), and Yangchangzi gully (0.3559). In total, the results based on the intuitionistic fuzzy sets-TOPSIS model reflect the risk level of debris flow hazards accurately and further determine the risk ranking of debris flow hazards for different gullies at the same level.

5. Discussions and Comparative Analysis

5.1. Comparison with Existing Techniques

(1) Liu X.L (1996) presented a technique for the risk estimation of debris flow based on the Liu.X.L model. Many factors of debris flow and interaction influence of different factors are considered in the Liu X.L model, and uncertainty and fuzziness of risk level about the debris flow are not considered, so Liu X.L model requires vast datum and many investigations, and the workload is great. While our proposed model overcomes this deficiency of Liu.X.L model, relative to Liu.X.L model, the proposed model in the paper not only deals with vague information, but also eases our workload, and the proposed method improved the efficiency vastly.

(2) Intuitionistic fuzzy sets proposed by Atanassov (1983) have been applied to assess the risk level of debris flow. But it can not precisely express which indices require more to be supported; intuitionistic fuzzy sets-TOPSIS model can solve the issue; the maximum membership degree that is closest to the positive ideal solution and most far from the negative ideal solution is regarded as the most appropriate basis of risk level in the debris flow hazards to cover the level ranges.

5.2. Advantages of the Proposed Model. By comparing this approach with conventional Liu X.L model, and actual investigation, the advantages of the suggested method can be summarized as follows:

(1) Their judgments under inherent uncertainty in the proposed model can be conveyed. More significantly, the degree of indeterminacy can be handled adequately in the evaluation.

(2) In comparison with the traditional fuzzy mathematical method, the proposed model has the sufficient usage of original datum, minor information loss, and wider application. And it can precisely determine which indexes require more to be supported.

(3) Relative to the traditional assessment method, the proposed method not only can deal with vague information, but also can ease our workload, and the efficiency and accuracy can be improved.

6. Conclusions and Future Directions

Considering One-time discharge of debris flow (X1), the reserves of loose solid sources (X2), the ratio of silt supply length (X3), the watershed area (X4), the length of the main ditch (X5), the relative height difference in the watershed (X6), the bending coefficient of the main ditch (X7), the mean gradient of the main ditch (X8), and the 24-hour maximum rainfall (X9), a new assessment method is introduced in this paper to assess the risk level of debris flow hazards in the Duba River watershed based on the Intuitionistic Fuzzy Sets-TOPSIS model. The decisive matrix of the debris flow is established at first. Then, the weighting coefficients of the different indexes were obtained by using the entropy weighting method. Finally, the risk level of debris flow in Duba river watershed is determined using the degree of membership.

The present model is applied to assess the risk level of debris flow hazards in the Duba River watershed. Relative to the other methods, Intuitionistic Fuzzy Sets-TOPSIS theory need not construct the complex prediction model and high dimensional calculation; its calculative process is convenient and straightforward. Finally, its results are compared with the actual investigation and Liu XL Model, and the results obtained by three various methods are consistent; its accurate rate arrives at 100%. This demonstrates the suggested method has certain reliability and veracity. This proposed model can convey their judgments under inherent uncertainty and can handle the degree of indeterminacy adequately in the evaluation, And it can also precisely determine which indexes require more to be supported. So, the proposed model is widely applied in the civil engineering.

The final risk levels of debris flow hazards in the Duba River watershed are III. These conclusions mean that the risk levels of debris flow hazards in the Duba river watershed are high, so the corresponding measurement should be adopted to prevent debris flow hazards in the Duba River watershed. Final conclusions are drawn that it is feasible to assess the risk level of debris flow hazards by using the proposed model, and it also provides more details about the risk assessment of debris flow hazards. In all, the results of the proposed Intuitionistic Fuzzy Sets-TOPSIS model are highly consistent with the current specifications; it not only reflects the risk level accurately, but also further determines the risk ranking of debris flow hazards for different gullies at the same level. And it can provide a new method and thoughts for the risk assessment of debris flow hazards in the future. And the combination of the TOPSIS and intuitionistic fuzzy sets methods has various potential applications for risk level of natural hazards. The application of the proposed model can be extended to stable assessment of surrounding rocks in the tunnel, the evaluation of rock burst intensity, and even the stable prediction of the landslide. These results can provide many predictions for the prevention of natural hazards.

Although the Intuitionistic Fuzzy Sets-TOPSIS model improves the development of assessment theory, however, the model still shows certain limitations. For example, determination of certain assessment indices and weight coefficients has a certain subjectivity. Due to the comprehensiveness of influencing indexes, so the assessment method has a strong dependence on actual data. In future work, concept of spherical fuzzy sets can be applied; it is the development of intuitionistic fuzzy sets theory, it provides a larger preference volume in 3D space for decision-makers, T-spherical fuzzy method [28–30] is used in solving a multiple criteria selection problem, its range varies from ordinary fuzzy sets to spherical fuzzy sets, the space is extended from 2D to 3D, this can overcome the shortcoming of intuitionistic fuzzy sets, and T-spherical fuzzy method will be our future direction to assess the risk level of debris flow.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the cross project in Nanyang Institute of Technology (520009); The Start-Up Foundation (510126), Sichuan Science and Technology Program (No : 2020YJ0424), Regional Innovation Cooperation Programs of Sichuan province (2021YFQ0050),.National Natural Foundation in China (no. 41672357), Surface Project of Chongqing Natural Science Foundation (cstc2020jcyj-msxmX0904), and The Scientific and Technological Projects of Henan Province (222102320296).

References

[1] X. L. Liu and S. L. Zhan, "Evaluation of the risk degree of debris flow in ravine," *Journal of Soil & Water Conservation*, vol. 7, no. 2, pp. 20–25, 1993.

[2] X. B. Gu, Y. Ma, Q. H. Wu, X. J. Ji, and H. Bai, "The risk assessment of landslide hazards in Shiwangmiao based on intuitionistic fuzzy sets-Topsis model," *Natural Hazards*, vol. 111, no. 1, pp. 283–303, 2021, https://doi.org/10.1007/s11069-021-05053-5.

[3] X.-P. Zhou, X.-B. Gu, M. H. Yu, and Q.-H. Qian, "Seismic bearing capacity of shallow foundations resting on rock masses subjected to seismic loads," *KSCE Journal of Civil Engineering*, vol. 20, no. 1, pp. 216–228, 2016.

[4] J.-W. Chen and X.-P. Zhou, "The enhanced extended finite element method for the propagation of complex branched cracks," *Engineering Analysis with Boundary Elements*, vol. 104, pp. 46–62, 2019.

[5] Y. Zhao, C. Du, J. Bi, C. Wang, Experimental investigation of triaxial compression and permeability of gritstone in geothermal environment," *Bulletin of Engineering Geology and the Environment*, vol. 80, no. 9, pp. 6971–6988, 2021.

[6] D. J. Varnes, *Landslide hazard zonation:a Review of Principles and Practive*, France : Paries, 1984.

[7] T. Glade, "Linking debris-flow hazard assessments with geomorphology," *Geomorphology*, vol. 66, no. 1–4, pp. 189–213, 2005.

[8] R. Hollingsworth and G. S. Kovacs, "Soil slumps and debris flows: prediction and p," *Environmental and Engineering Geoscience*, vol. xviii, no. 1, pp. 17–28, 1981.

[9] M. T. Eldeen, "Predisaster physical planning: integration of disaster risk analysis into physical planning - a case study in Tunisia," *Disasters*, vol. 4, no. 2, pp. 211–222, 1980.

[10] Y. Zhao, D. Ding, J. Bi, C. Wang, and P. Liu, "Experimental study on mechanical properties of precast cracked concrete under different cooling methods," *Construction and Building Materials*, vol. 301, no. 27, pp. 124141–141, 2021.

[11] W. Wu, "Debris flow risk assessment based on grey correlation analysis method a case study of Yinpohe debris flow in Lushui County," *Geological Disasters and Environmental Protection*, vol. 3, p. 21, 2017.

[12] L. L. Cao, L. R. Xu, and S. Y. Chen, "Assessment of debris flow hazard based on fuzzy network," *Hydrogeology & Engineering Geology*, vol. 42, no. 2, 2014.

[13] J. H. Wang, "The application of fuzzy comprehensive evaluation model based on analytic hierarchy process in risk assessment of debris flow gully in Kangle County," *Chinese Journal of Geological Hazard and Control*, vol. 28, no. 3, p. 54, 2017.

[14] H. Chu, G. Xu, and N. Z. P. J. Yasufuku, "Risk assessment of water inrush in karst tunnels based on two-class fuzzy comprehensive evaluation method," *Arabian Journal of Geosciences*, vol. 10, no. 7, p. 179, 2017.

[15] S. J. Walsh and D. R. Butler, "Morphometric and multispectral image analysis of debris flows for natural hazard assessment," *Geocarto International*, vol. 12, no. 1, pp. 59–70, 1997.

[16] X. B. Gu, S. T. Wu, X. J. Ji, and Y. H. Zhu, "The risk assessment of debris flow hazards in b gully based on the entropy weight-normal cloud method," *Advances in Civil Engineering*, vol. 2021, pp. 1–11, 2021.

[17] X. B. Gu, J. L. Shao, and S. T. Wu, "The risk assessment of debris flow hazards in Zhouqu based on the projection Pursuit classification model[J]," *Geotechnical & Geological Engineering*, vol. 8, pp. 4–17, 2021.

[18] M. Akram, A. Luqman, J. C. R. Alcantud, and A. Luqman, "Risk evaluation in failure modes and effects analysis: hybrid TOPSIS and ELECTRE I solutions with Pythagorean fuzzy information," *Neural Computing & Applications*, vol. 33, no. 11, pp. 5675–5703, 2020.

[19] T. S. Zhao, Y. L. Sun, and L. R. Wang, "Sensitivity evaluation of mountain roads based on TOPSIS model," *Shaanxi Water Resources*, vol. 12, pp. 10–12, 2020.

[20] A. Luqman, M. Akram, and J. C. R. Alcantud, "Digraph and matrix approach for risk evaluations under Pythagorean fuzzy information," *Expert Systems with Applications*, vol. 170, p. 114518, 2021.

[21] M. Sarwar, M. Akram, and P. Liu, "An integrated rough ELECTRE II approach for risk evaluation and effects analysis in automatic manufacturing process," *Artificial Intelligence Review*, vol. 54, no. 6, pp. 4449–4481, 2021.

[22] J. Zhou, X. Li, and X. Shi, "Long-term prediction model of rockburst in underground openings using heuristic algorithms and support vector machines," *Safety Science*, vol. 50, no. 4, pp. 629–644, 2012.

[23] Z. H. Xu, S. C. Li, and L. P. Li, "Risk assessment of water or mud inrush of karst tunnels based on analytic hierarchy process," *Rock and Soil Mechanics*, vol. 32, pp. 1757–1766, 2011.

[24] V. P. Singh, "Entropy theory and its application in environmental and water engineering," *John Wiley & Sons*, vol. 662, 2020.

[25] K. T. Atanassov, *Intuitionistic Fuzzy Sets*, VII ITKR's Session, Sofia, Bulgarian, 1983.

[26] C. Luo, *Risk Assessment and Prevention Research of Debris Flow in Yangjia Gully," Beichuan. PhD Thesis*, Southwest University of Science and Technology, Mianyang, China.

[27] X. L. Liu, "Assessment on the severity of debris flows in mountainous creeks of southwest China," *Proceedings of International Symposium of Interpravent 1996 —Garmisch-PartenkirchenTagungspublikation, Band*, vol. 4, pp. 145–154, 1996.

[28] K. Ullah, H. Garg, T. Mahmood, and N. Z. Jan, "Correlation coefficients for T-spherical fuzzy sets and their applications in clustering and multi-attribute decision making," *Soft Computing*, vol. 24, no. 3, pp. 1647–1659, 2020.

[29] P. Liu and D. Wang, "An extended taxonomy method based on normal T-spherical fuzzy numbers for multiple-attribute decision-making," *International Journal of Fuzzy Systems*, vol. 24, no. 1, pp. 73–90, 2022.

[30] M. E. I.-Q. I. N. Wu, T. I. N. G.-Y. O. U. Chen, and J. I. A. N.-P. I. N. G. Fan, "Divergence measure of T-spherical fuzzy sets and its applications in pattern recognition," *IEEE Access*, vol. 8, 2020.