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XVIII World Water Congress
International Water Resources Association (IWRA)

Risk Assessment of Landslide Dam Failure

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XVIII WORLD WATER CONGRESS Water for All Harmony between Humans and Nature
第18届世界水资源大会 水与万物：人与自然和谐共生

Content

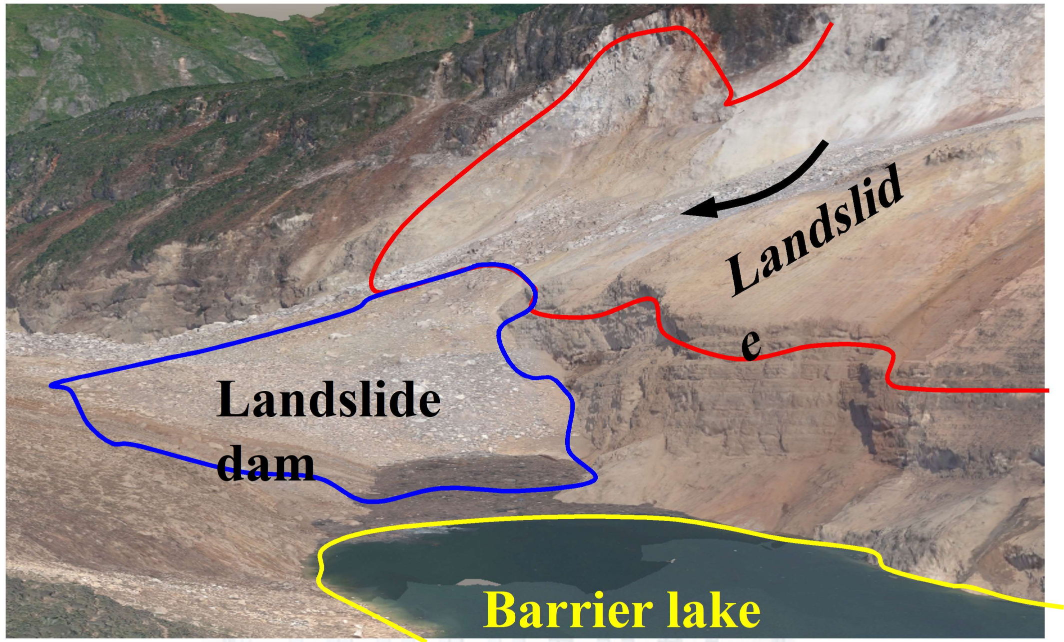
- **Background**
- **Risk assessment for landslide breach disasters**
- **Conclusions**

Background

Formation of barrier lake

- According to a statistical analysis of landslide dams worldwide, the most important triggering factors of river-damming landslides were earthquake and rainfall. The resulting landslide is the most popular form.

Formation process of barrier lake

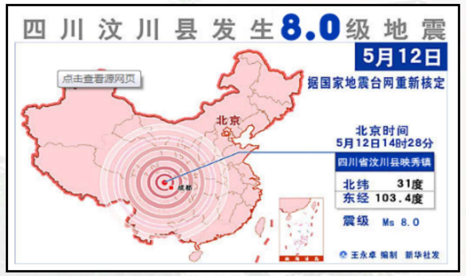


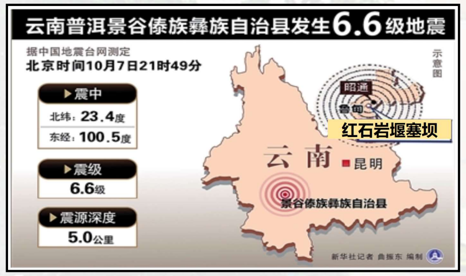
Earthquake

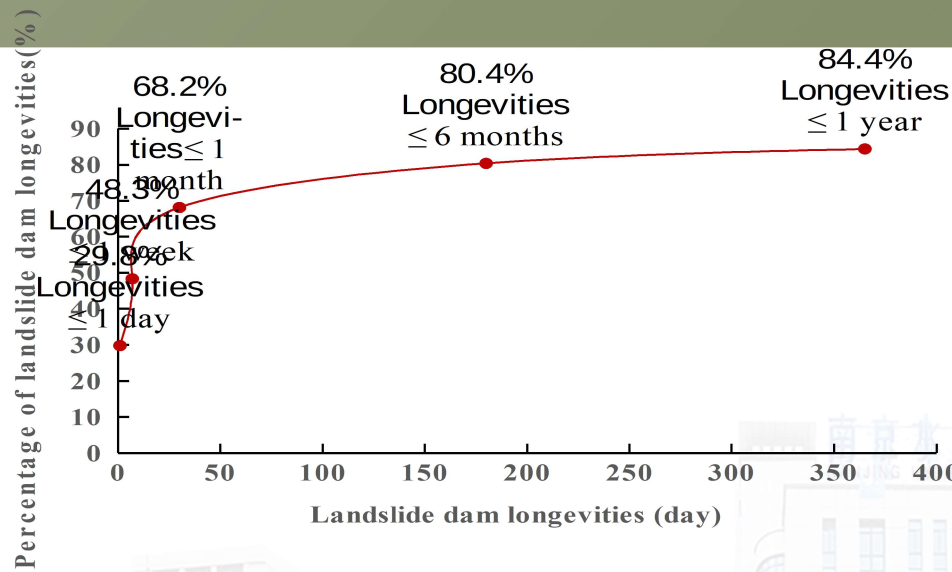
Rainfall

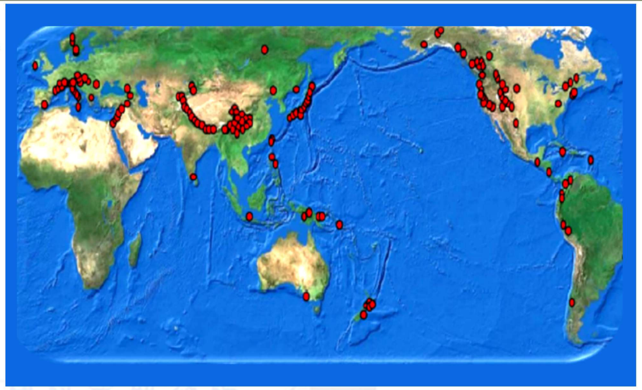
Background

- Landslide dams are common worldwide, especially in active mountain regions. They are extremely dangerous phenomena, as they may trigger dam-break floods that can affect large areas downstream. They are widely distributed in more than 1400 places all over the world. There are more than 800 cases in China.
- 85% of the landslide dams will breach in one year, so the dam-breaking risk of the landslide dam is much higher than that of the artificial embankment dam.

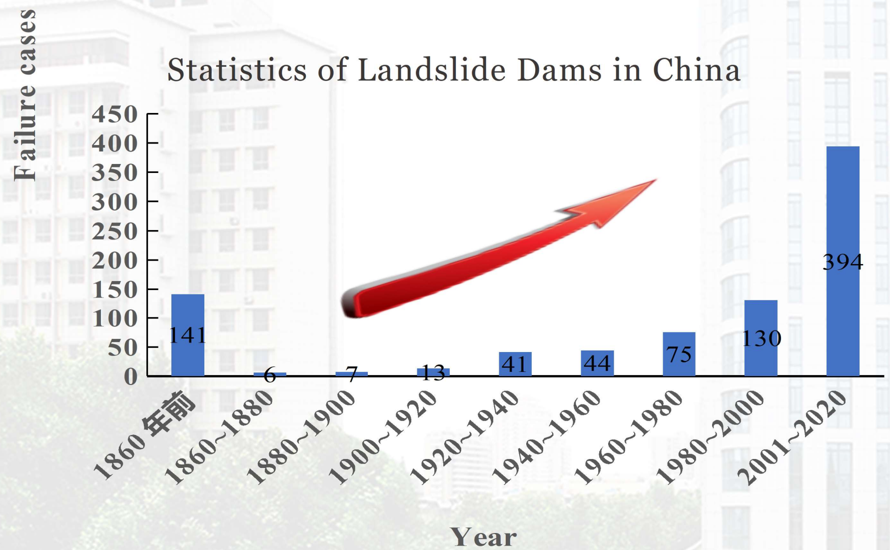


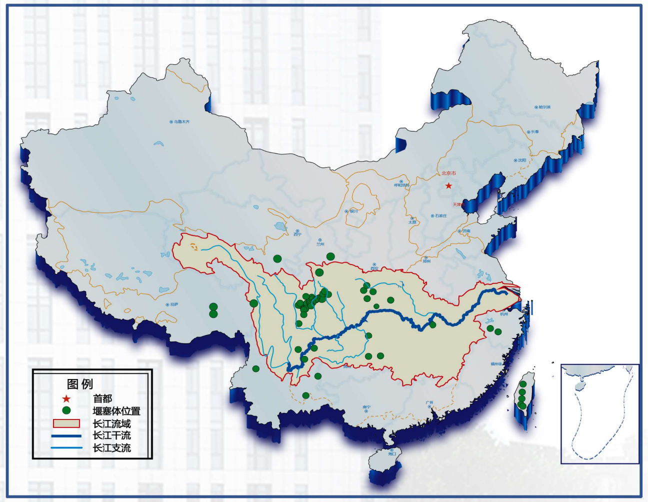






Distribution of large landslide dams in the world





Distribution of classical landslide dams in China

In recent years, due to the combined effects of geological structures, meteorological conditions, and hydrology, the upstream areas of the Yangtze River Basin in China have experienced a high occurrence and frequency of landslide dam formation.

Background

Hazards of landslide dams

Once landslide dams breached, massive flooding may occur in a short time, posing a great threat to the lives and properties of downstream residents. So accurate prediction of landslide dam breach process is of great importance for the emergency response.

Tangjiashan Landslide Dam
Failure time: 2008
Peak discharge: 6500 m^3/s
More than 250,000 people were evacuated.

Xiaogangjian Landslide Dam
Failure time: 2008
Peak discharge: 3950 m^3/s
More than 5,000 people were evacuated.

Baige Landslide Dam
Failure time: 2018
Peak discharge: 31000 m^3/s
Nearly 75,000 people were evacuated.

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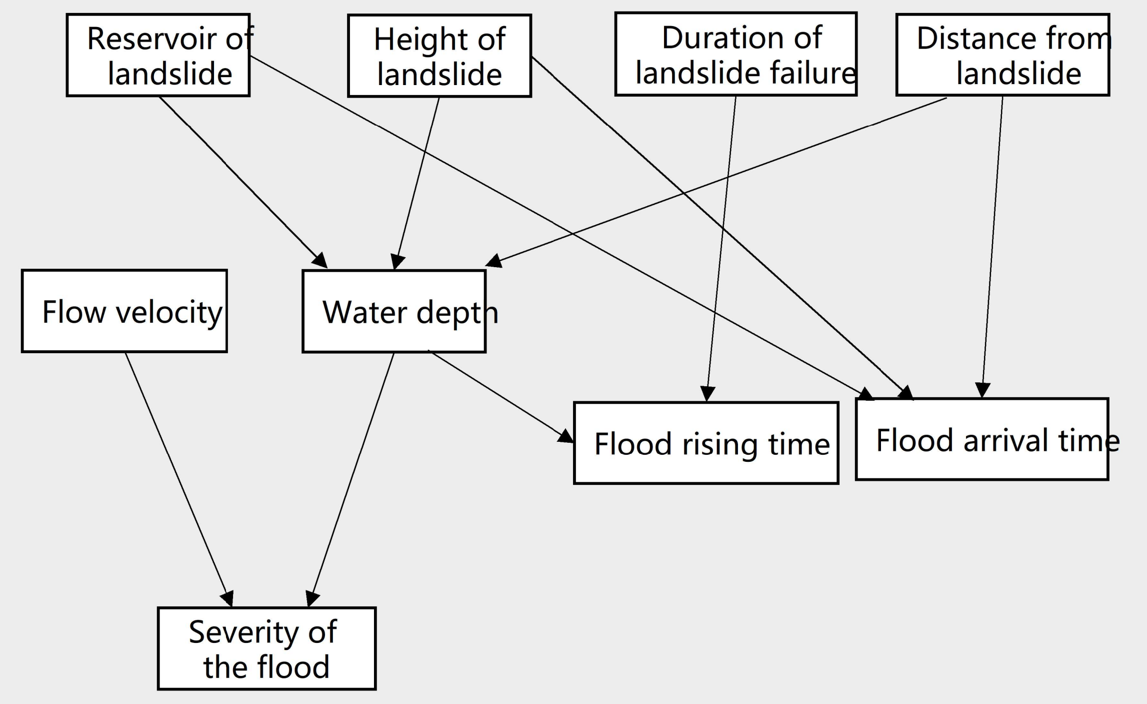
Risk assessment for landslide breach disasters

Bayesian network for flood risk assessment of landslide failure

- ✓ By simulating the evolution of flood caused by landslide failure, analyze the flooded area, the water depth at a certain location downstream, the flow velocity, and the time of peak flood arrival.
- ✓ Establishing the network model based on the historical data and and incorporating Monte Carlo simulation methods.



Bayesian network for breach flood of landslide

Risk assessment for landslide breach disasters

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Quantification of Bayesian network nodes for the risk of flood caused by landslide failure

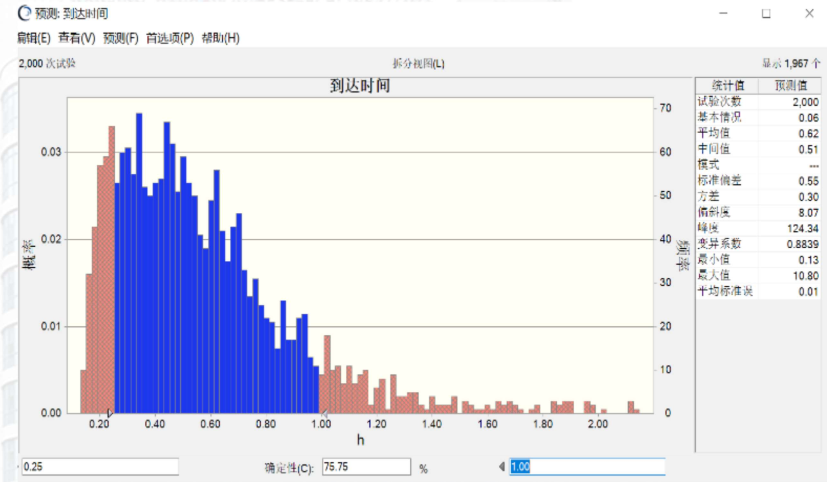
✓ Quantifying nodes for the severity of the flood and the duration of the flood evolution, and utilizing Monte Carlo simulation to assess the probability distribution of flood arrival time.

Quantifying nodes for the severity of the flood

- **Height and reservoir of landslide** → Quantification of case data in the database
- **Distance from landslide** → Measure the distance from the landslide to the affected area.
- **Water depth** → $$H_x = H_0\left[\frac{1}{1+\frac{4a^2(2m+1)H_0^{2m+1}}{m(m+1)^2 i_0 V_l^2}x}\right]^{\frac{1}{2m+1}}$$
- **Flow velocity** → $$v_x = \frac{Q_{xm}}{a\cdot H_x^m} \qquad Q_{xm} = \frac{V_l}{\frac{V_l}{Q_m}+\frac{x}{vK}}$$

Quantifying time nodes for the evolution of the flood.

- **Duration of the flood** → $$\frac{T_f}{T_0} = \left(\frac{H_d}{H_0}\right)^{0.293}\left(\frac{V_l^{\frac{1}{3}}}{H_d}\right)^{0.723} e^{a_{10}}$$
- **Flood arrival time** → $$T_1 = K_1\frac{x^{1.75}(10-h_0)^{1.3}}{V_l^{0.2}H_d^{0.35}}$$
- **Flood rising time** → $$T_2 = B_t \cdot \alpha\beta\gamma$$



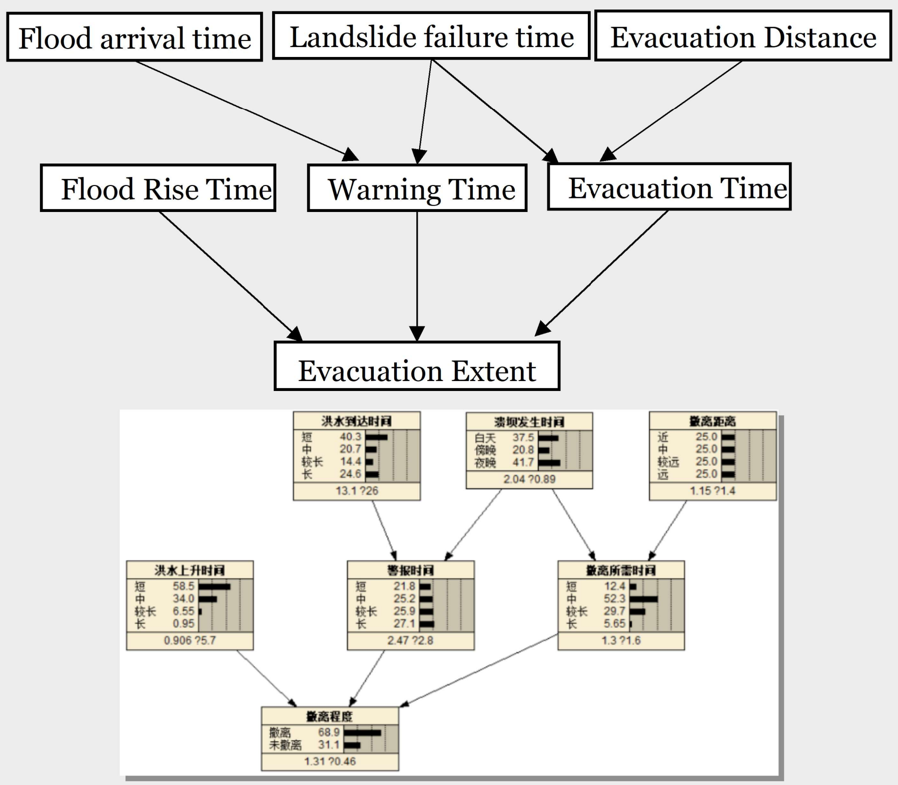
Monte Carlo method simulates the probability distribution of flood arrival time

Risk assessment for landslide breach disasters

Model for assessing the loss of life caused by landslide failure

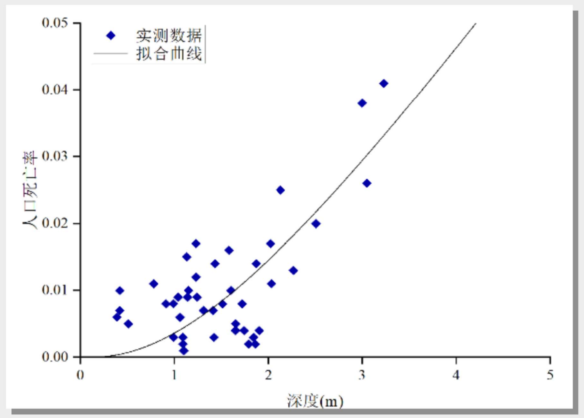
✓ By collecting and analyzing historical data, combining Bayesian theory and Monte Carlo method, we explore the causal relationships among various influencing factors and establish a model for assessing the loss of life due to the failure of the landslide.

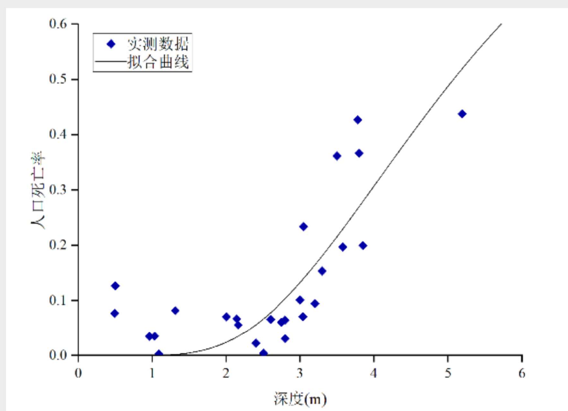
Population Evacuation Model



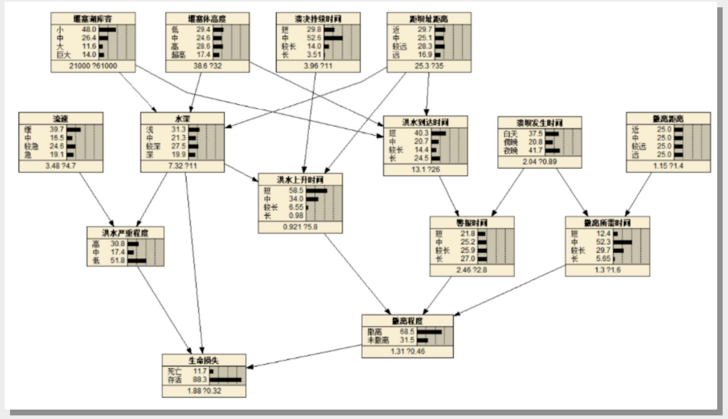
Bayesian network of evacuation process

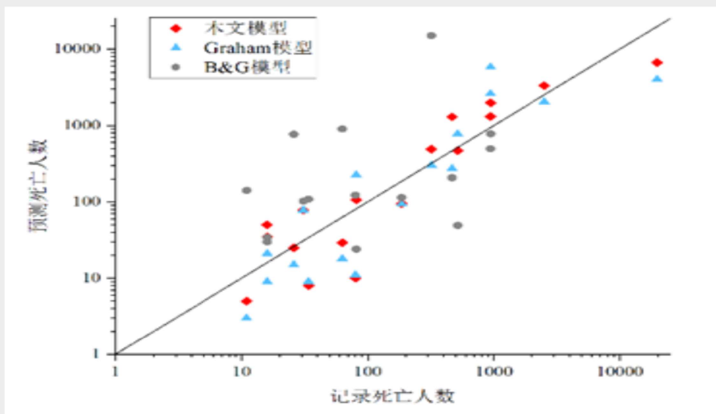
Fitting of Flood Severity Zones





Quantitative Assessment Model for Loss of Life





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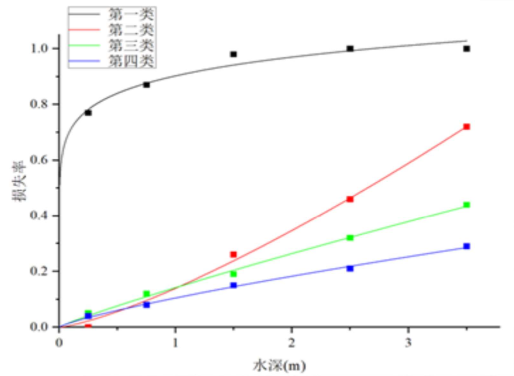
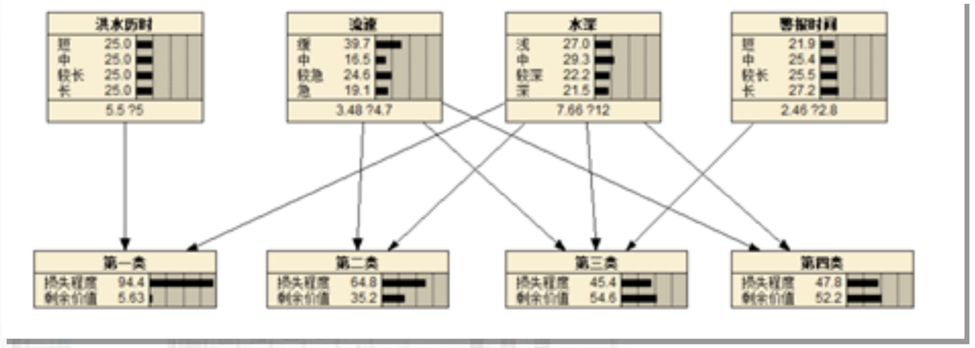
Model for assessing the economic losses caused by landslide failure

✓ By combining historical data, establish various property-depth loss rate functions, and then adjust the loss rate by considering the influencing factors of different types of properties, aim to establish a regional economic loss assessment model.



Depth—loss rate functions



Bayesian network for economic losses

Loss category	Water depth (m)					Curve equation
	0 ~ 0.5	0.5 ~ 1	1 ~ 2	2 ~ 3	>3	
Category 1: Agriculture/Fishery	76.9	87.4	97.8	100	100	$R(h)=0.105x^{0.798}$
Category 2: Forestry/ Livestock	0.1	8.2	25.6	46.2	71.6	$R(h)=0.903x^{0.104}$
Category 3: Industry/ Real Estate	4.7	12.1	19.3	32.2	44.3	$R(h)=0.14x^{1.309}$
Category 4: Transportation/Water Conservancy	3.6	8.2	15.2	21.1	28.9	$R(h)=0.142x^{0.893}$

Recommended value for economic loss rates

Functions for economic losses

$$R_{Loe}(i) = (F_i - F_i') / F_i$$

$$R_{Loe}(i,h) = \sum_j (Gr_{ij} \cdot R_{Loe}(i,j,h))$$

$$R_{Loe}(i) = R_{Loe}(i,h) \cdot f_t \cdot f_v \cdot f_T$$

$$L_D = \sum_i F_i \cdot R_{Loe}(i)$$

$$L_I = \sum_i F_i \cdot R_{Loe}(i) \cdot p_i$$

$$L_E = (L_D + L_I) \cdot (r+1)^t$$

$$Loe = \sum_k^n L_E(k)$$

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● Model for assessing the ecological losses caused by landslide failure

✓ Quantitative assessing social influence and ecological losses caused by landslide failure based on the Social, Cultural, and Ecological Environment of flood influent zone, and thus establish the assessment method of ecolo lgical losses.

Impact level	At-risk population	f_1	Importance level of cities	f_2	Importance level of facilities	f_3	Cultural relics and historic sites	f_4
Mild	1-10	1~1.2	Retail investors	1	General facilities	1	General cultural relics	1
Moderate	10-10^3	1.2~1.6	Rural areas	1.3	Moderately important facilities	1.2	County-level cultural relics	1.2
Severe	10^3-10^5	1.6~2.4	Towns	1.6	City-level important facilities and enterprises	1.5	Provincial-level cultural relics	1.5
Critical	10^5-10^7	2.4~4	County-level cities	2	Provincial-level important facilities and enterprises	1.7	National-level cultural relics	2
			Prefecture-level cities	3				
Extremely critical	$>10^7$	4~5	Provincial capital cities	4	National-level important facilities and enterprises	3	World-level cultural relics	2.5
			Capital city	5				

Recommendation table for the coefficient of social impact degree

Impact level	River channel morphology	f_5	Ecological hábitats	f_6	Cultural landscapes	f_7	Industrial pollution,	f_8
Mild	Slight damage to river channels	1	General fauna and flora	1	Slight damage to municipal-level landscapes	1	Minimal pollution	1
Moderate	General rivers suffer moderate damage	1.3	Valuable fauna and flora	1.2	Damage to municipal-level landscapes	1.2	General factories	1.2
Severe	Major rivers suffer moderate damage	1.6	Relatively precious fauna and flora	1.5	Damage to provincial-level landscapes	1.5	Large-scale factories	1.6
Critical	General rivers suffer significant damage	2	Rare fauna and flora	1.7	Damage to national-level landscapes	1.7	Industrial-scale factories	2
	Major rivers suffer significant damage	3						
Extremely critical	Diversion of general rivers	4	Globally endangered fauna and flora	2	Damage to world-level landscapes	2	Hazardous chemical plants	3
	Diversion of major rivers	5					Nuclear power plants	4

Recommendation table for the coefficient of ecological impact degree

Ecological loss value：

$$Los = \prod_{k}^{8} f_k$$

Impact level	f_{se}
Moderate	1~10
Severe	10~10^2
Critical	10^2~10^3
Extremely critical	10^3~10^4

Ecological loss classification table

- **Comprehensive Assessment Model for Losses caused by landslide failure**

✓ Normalizing the three types of losses based on their degree of impact, in order to conduct a quantitative analysis of different losses using a unified standard.

Index of life losses → $$Lol = \sum_{k}^{n} N_k \cdot R_{Lol}(k)$$

Index of economic losses → $$L_E = \sum_{i} F_i \cdot R_{Loe}(i) \cdot (p_i + 1) \cdot (r + 1)^t \qquad Loe = \sum_{k}^{n} L_E(k)$$

Index of ecological losses → $$Los = \prod_{k}^{8} f_k$$

Comprehensive loss rate calculation method for landslide failure → $$F = F_l \cdot S_l + F_e \cdot S_e + F_s \cdot S_s$$

Normalization function

$$\begin{cases} F_l = \dfrac{1}{5^{0.1}}(\lg Lol)^{0.1} \\ F_e = \dfrac{1}{5^{0.2}}(\lg \dfrac{Loe}{10})^{0.2} \\ F_s = \dfrac{1}{4}\lg Los \end{cases}$$

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Conclusions

- A quantification of flood severity and evolution time based on Bayesian networks and Monte Carlo simulation methods has been conducted.
- An evaluation model for the life loss, ecological loss, and economic loss caused by dammed lake breaches has been proposed, and a comprehensive loss assessment model has been established.

Evaluation of landslide dam failure disaster losses

Landslide dam failure		
Characteristics	➢ Mainly affects the downstream area ➢ Higher flow velocity and deeper water depth ➢ Shorter duration of flooding ➢ Higher sediment concentration in the floodwater and stronger destructive power	
Classification of losses	**Characteristics**	**Evaluation methods**
Life losses	➢ Characteristics of breach ➢ Alarm time ➢ Evacuation time required	➢ Bayesian network ➢ Monte carlo ➢ Historical data
Economic losses	➢ High destructive power ➢ Considering the impact of water depth, flow velocity, and alarm time	➢ Bayesian network ➢ Monte carlo
Ecological losses	➢ High flow velocity and sediment load ➢ Changes in downstream river channel morphology, habitat and landscape destruction, industrial pollution	➢ F-N curve

Thank you!