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Safety Risk Assessment of Cave Adventure Tourism Projects: A Case Study of Shierbeihou, Guizhou, China

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ABSTRACT

Cave adventure tourism has expanded in karst scenic areas, but its rapid development has increased operational safety risks that are difficult to address through general tourism safety management. This study develops and applies a safety risk assessment framework for cave adventure tourism projects in scenic areas. A preliminary indicator pool was established through a literature review, field observations, and expert consultations. The indicators were refined through three rounds of Delphi consultation with 11 experts, weighted using the analytic hierarchy process, and applied through fuzzy comprehensive evaluation in Shierbeihou Scenic Area. The final framework included four primary indicators, nine secondary indicators, and 46 tertiary indicators. Facility risk received the highest primary weight (0.3086), followed by personnel, management, and environmental risk. Based on 447 valid questionnaires, the overall fuzzy evaluation score was 2.3338, placing the case in the low-risk category on the study's five-level perception-based scale. Key risk points included accidental injury, tourists' physical and mental health, guide emergency response ability, safety training, emergency response timeliness, and facility inspection and maintenance. The framework provides a basis for prioritizing safety management, facility maintenance, and emergency preparedness in cave adventure tourism projects.

1. INTRODUCTION

The rapid growth of adventure tourism has changed the way safety risks are understood and managed in tourism destinations, particularly in outdoor and nature-based settings. Conventional sightseeing tourism typically emphasizes visitor flow, service facilities, and standard emergency procedures. In adventure tourism, safety is more closely tied to the activity itself. Participants face unfamiliar environments, physical demands, equipment use, and on-site decision-making, making risk management a concern for both visitors and operators [1, 2]. Previous research suggests that eliminating all accidents in outdoor recreation is unrealistic, but their frequency and severity can be reduced through risk identification, preventive measures, safety training, equipment control, and effective on-site management [3]. However, adventure tourism safety has yet to be researched to the extent its practical significance would suggest, particularly in accident monitoring, risk factor identification, assessment models, and operational safety systems [4]. In China, safety and risk management in adventure tourism have also been discussed from the perspectives of risk classification, risk warning systems, risk rescue systems, and risk management models [5]. With the increasing accessibility of adventure tourism for mass tourists, project-specific safety risk assessment is increasingly required.

Cave adventure tourism is a demanding form of adventure tourism because it takes place in enclosed, humid, dimly lit, and geologically complex underground environments. Cave adventure tourism differs from developed show-cave sightseeing in that it is likely to involve semi-open or non-standardized routes, enclosed underground spaces, low light levels, high humidity, rough terrain, and greater reliance on guides, equipment, facilities, route planning, and emergency preparation. Access for rescue is often restricted, and visitor safety depends on route design, guide skills, equipment condition, facility maintenance, and the capacity to respond to emergencies. Studies of cave tourism have identified risks including rockfall, roof collapse, poisoning and suffocation, infection, electric shock, and difficulties in emergency responses [6, 7]. New research on show caves and on karst geotourism also suggests that cave tourism can affect sensitive cave ecosystems, tourist safety, environmental stability, and the management of carrying capacity. The Brazilian and Indonesian studies on speleotourism and cave ecotourism also indicate that the use of caves is not only a matter of tourism development but also of management institutions, community involvement, environmental protection, and sustainability [8, 9]. In addition, biosecurity research indicates that cavers and visitors to caves, their clothing and equipment, can be vectors of ecological or disease risk, and therefore both cave tourism and cave conservation must be managed together [10]. Cave adventure tourism is considered a distinctive activity in the Chinese karst environment, and related research has

highlighted the need for management regulations, practitioner training, service specifications, and a safety-guarantee system [11, 12]. These findings show that safety risks in cave adventure tourism extend beyond environmental hazards and arise from interactions among people, facilities, management, and the environment.

Several research streams are relevant to this problem. Outdoor recreation and adventure tourism studies have examined risk perception, risk behavior, injury prevention, equipment, and risk matrices, emphasizing the need to tailor risk management to activity context and participant characteristics. Tourism risk assessment has also moved from general destination risk toward more complex tourism spaces; studies of cross-regional tourism corridors, for example, identify environmental conditions, infrastructure, location, economic foundations, and management capacity as major determinants of tourism safety and sustainable risk governance [13]. Safety-engineering research likewise emphasizes context-specific risk identification, classification, capacity assessment, and targeted control [14-16]. Together, these studies support a risk-governance approach that assesses human behavior, facility conditions, management capacity, and environmental uncertainty jointly rather than in isolation.

Despite these contributions, research still lacks an integrated operational framework for project-level safety assessment in cave adventure tourism. Cave tourism studies have focused mainly on resource development, environmental protection, visitor experience, safety cognition, and sustainable management, while adventure tourism research has emphasized risk perception, self-protective behavior, risk communication, and revisit intention. Existing risk-assessment studies provide relevant methods, including indicator systems and multi-source analysis [17]. Delphi consultation offers a structured approach to expert consensus [18]; analytic hierarchy process (AHP) provides a basis for determining relative indicator weights [19]; and fuzzy methods support evaluation under subjective uncertainty [20, 21]. Yet few studies connect risk identification and screening with weighting and case-based evaluation for enclosed cave settings. A project-level framework is therefore needed to identify major risk dimensions, quantify relative importance, and locate priority risk points.

In order to address this gap, this study develops a safety risk assessment indicator system for cave adventure tourism projects and applies it to Shierbeihou Scenic Area in Guizhou Province, China. Candidate indicators were identified from the literature, field observations, and expert input, refined through Delphi consultation, weighted with AHP, and evaluated using fuzzy comprehensive evaluation to establish a systematic framework for identifying, prioritizing, and managing key safety risks in cave adventure tourism operations.

The study addresses three questions: What are the key dimensions of safety risk in cave adventure tourism projects? What is the relative importance of the risk factors within the assessment system? Can the framework identify priority risk points in a real cave adventure tourism project? The study treats cave adventure tourism as a project-level setting in which personnel, facilities, management, and environmental risks interact.

The methodological contribution lies in integrating risk identification, Delphi-based indicator refinement, AHP weighting, and fuzzy comprehensive evaluation into a project-level assessment pathway for cave adventure tourism.

2. METHODOLOGY

2.1 Research design

This study combined indicator development, expert-based weighting, and empirical case evaluation in three sequential phases.

First, a preliminary indicator pool was developed from the literature, field observations, and expert input. Second, the Delphi method was used to screen and revise the indicators, and AHP was used to determine their relative weights. Third, the framework was applied to the Shierbeihou cave adventure tourism project using questionnaire data and fuzzy comprehensive evaluation.

2.2 Study area and data sources

The case study was the cave adventure tourism project at Shierbeihou Scenic Area in Suiyang County, Zunyi City, Guizhou Province, China. The project is closely related to Shuanghe Cave National Geopark and has typical karst cave characteristics. Its operation involves tourists, specialist guides, equipment and facilities, route organization, emergency rescue, medical support, and environmental risk factors, making it an appropriate case for applying the proposed framework.

Three data sources were used. Literature and policy materials on cave tourism, adventure tourism, tourism safety, and scenic-area management informed the initial risk pool. Field observations at Shierbeihou Scenic Area from 1 to 7 April 2026 covered the cave route, staff arrangements, equipment condition, warning signs, site management, and emergency arrangements. The empirical questionnaire survey was conducted on 5 and 6 April 2026.

Prior to data collection, research permission and informed consent documentation were obtained from Universitas Negeri Jakarta. Participation was voluntary and anonymous, and respondents were informed that the data would be used solely for academic research. The research permission number was 1724/UN39.6SP/sLT/2026.

2.3 Indicator development and Delphi consultation

The first indicator pool was established in the context of the operational characteristics of cave adventure tourism projects. Four general categories of risk emerged: personnel risk, facility risk, management risk and environmental risk. The first-level indicators, second-level indicators, and third-level candidate indicators were collected from the literature review, field observations, and experts' suggestions as an initial pool of indicators, with 4, 10, and 53 indicators, respectively.

Following the Delphi consensus approach, 11 experts were purposively recruited for three rounds [18]. Eligibility required more than 5 years of relevant experience; university academics had to hold at least an associate professor appointment, scenic-area personnel at least a deputy manager position, and technical specialists had to be certified national mountain-rescue trainers. The panel included scenic-area managers, a project manager, mountain-rescue trainers, and university researchers with 7-31 years of relevant experience; individual qualifications are reported in Table A1. All 11 experts completed all three anonymous rounds (100% response in each round; no attrition; Table A2). In each round, experts rated indicator importance and applicability and

provided written comments.

Indicator screening combined two quantitative criteria with written expert comments. With 11 experts, a full-score ratio of 0.19 or lower corresponds to no more than two experts assigning the highest importance rating and was used as a study-specific low-recognition threshold. A coefficient of variation greater than 0.25 was treated as substantial dispersion, consistent with previous Delphi indicator-development research [19]. Indicators meeting either criterion were flagged for deletion or review, and final decisions to remove, merge, revise, or retain items also considered the experts' written comments. The principal first-round changes are summarized in Table A3. After three rounds, the final system comprised four primary, nine secondary, and 46 tertiary indicators.

2.4 Weight determination using the analytic hierarchy process

After the indicator system was finalized, the 11 experts rated the relative importance of indicators on a 1-9 scale. The expert ratings were analyzed using AHP software, and judgment matrices were constructed for indicators within each hierarchical group [19]. Local weights were derived from these matrices. The complete group-level judgment matrices are provided in Tables A4-A17.

The global weight of each secondary indicator was calculated by multiplying its local weight by the corresponding primary weight. The global weight of each tertiary indicator was calculated by multiplying its local tertiary weight by the corresponding secondary and primary weights.

For each judgment matrix, the maximum eigenvalue, consistency index, and consistency ratio were calculated. A consistency ratio below 0.10 was considered acceptable. Observed values ranged from 0.0000 to 0.0422 (Table 1), and matrix-specific statistics are reported in Tables A4-A17. Kendall's W, rather than the consistency ratio, was used to describe agreement across the Delphi panel.

Local and global weights for all 46 tertiary indicators are provided in Table A18.

Table 1. Consistency statistics for analytic hierarchy process (AHP) judgment matrices

Indicator Layer	Number of Matrices	CR Range	Consistency Criterion
Primary indicators	1	0.0000	CR < 0.10
Secondary indicators	4	0.0000–0.0000	CR < 0.10
Tertiary indicators	9	0.0000–0.0422	CR < 0.10

2.5 Questionnaire survey and fuzzy comprehensive evaluation

The empirical survey was conducted on 5 and 6 April 2026 at Shuanghe Cave in Shierbeihou Scenic Area. Tourists participating in the cave adventure project were recruited on site by convenience sampling, while project managers and specialist guides involved in project operations were recruited purposively. The project served approximately 1,000 visitors per day, and the scenic area employed 334 staff across operational and support roles. A total of 458 questionnaires were returned. Eleven were excluded because of uniform response patterns (n = 9) or incomplete responses (n = 2), leaving 447 valid questionnaires (360 tourists and 87 practitioners; valid response rate, 97.5%). Responses were collected across four-time blocks on each survey day (Table A19), and respondent characteristics are summarized in Table A20.

Tourist and practitioner responses were pooled to estimate a mixed-stakeholder, perception-based risk profile. Because ordinary tourists may have limited access to internal operational information, scores for management, maintenance, professional qualifications, and medical support are interpreted as perceived risk signals rather than objective measures of operational performance. No respondent-specific weighting or subgroup analysis was applied.

The questionnaire contained the 46 final tertiary risk indicators. Each was rated from 1 (very low risk) to 5 (very high risk). Trained investigators explained the survey items before respondents rated each indicator based on direct participation, observation, or work experience. Response frequencies were converted to membership degrees to form the fuzzy evaluation matrix. The AHP weight vector was then combined with the matrix to obtain secondary, primary, and overall perception-based risk scores [21, 22].

The evaluation grade vector was defined as:

$$V = (v_1,v_2,v_3,v_4,v_5) = (1,2,3,4,5) \tag{1}$$

where, 1 represents very low risk, and 5 represents very high risk. The membership degree of indicator i belonging to grade j was calculated as:

$$r_{ij} = \frac{n_{ij}}{N_i} \tag{2}$$

where, n_{ij} represents the number of respondents selecting grade j for indicator i, and N_i represents the total number of valid responses for indicator i. The fuzzy evaluation matrix was expressed as:

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & r_{m3} & r_{m4} & r_{m5} \end{bmatrix} \tag{3}$$

The comprehensive membership vector was calculated as:

$$B = W \times R = (b_1,b_2,b_3,b_4,b_5) \tag{4}$$

where, W is the AHP-derived weight vector, R is the fuzzy evaluation matrix, and B is the comprehensive membership vector. The final comprehensive evaluation score was calculated as:

$$S = B \times V^T \tag{5}$$

Because the indicator system had a multi-level structure, the evaluation was conducted layer by layer, from tertiary indicators through secondary and primary indicators to the overall risk score.

2.6 Internal consistency and data suitability

Cronbach's alpha was used to assess internal consistency,

while the Kaiser-Meyer-Olkin measure (KMO) value and Bartlett's test of sphericity were retained as data-suitability checks. For the 447 valid responses across 46 items, Cronbach's alpha was 0.948, KMO was 0.958, and Bartlett's test was significant ($p < 0.001$).

3. RESULTS AND DISCUSSION

3.1 Development of the safety risk assessment indicator system

Safety risk factors were identified from the literature, field investigation, and expert consultation, yielding an initial pool of four primary, 10 secondary, and 53 tertiary indicators. Three rounds of Delphi consultation then assessed their importance, applicability, and wording before the final system was established (Table 2).

Expert agreement increased across the three Delphi rounds, with the highest Kendall's W values observed in round 3 for primary (0.815), secondary (0.695), and tertiary (0.715) indicators (all $p < 0.001$; Table A2).

The final safety risk assessment system for cave adventure tourism projects comprised four primary indicators, nine secondary indicators, and 46 tertiary indicators after screening, merging, and revision.

The final system organizes cave adventure tourism safety risk into four dimensions. Personnel risk covers tourists, specialist guides, and project managers; facility risk covers site and activity facilities; management risk covers emergency rescue and medical support; and environmental risk covers natural and social environments.

3.2 Weight distribution of safety risk indicators

AHP was used to determine the relative importance of the final indicators. Judgment matrices were constructed from the expert importance ratings for indicators within the same hierarchical group, and all matrices met the consistency criterion. The AHP weights represent relative importance within the assessment system, whereas the fuzzy scores represent perceived risk in the empirical case.

Facility risk had the highest primary weight (0.3086), followed by personnel risk (0.2838), management risk (0.2592), and environmental risk (0.1484). Together, the first three accounted for 85.16% of total weight, indicating that the framework places greater emphasis on controllable operational factors than on environmental hazards alone.

At the secondary level, activity facilities had the largest global weight (0.1650), followed by site facilities (0.1434), emergency rescue management (0.1313), medical support management (0.1279), and specialist guides (0.1123). Together, these five accounted for 67.99% of global weight (Table 3).

The weight structure therefore emphasizes facility condition, maintenance, guide competence, emergency response, and medical preparedness as central operational components of cave adventure tourism safety.

Table 2. Safety risk assessment indicator system for cave adventure tourism projects

Primary Indicator	Secondary Indicator	Tertiary Indicators
Personnel	Tourists	Safety awareness; accidental injury; self-management; learning ability; physical and mental health
Personnel	Specialist guides	Safety awareness; theoretical and technical competence; working conditions; work experience; emergency response awareness and ability; psychological quality; professional qualification; routine inspection; professional ethics
Personnel	Project managers	Safety training and education; management ability; safety awareness; professional ethics; qualification certification; emergency response awareness and ability
Facility	Site facilities	Safety warning signs in caves; safety protection facilities; congestion of experience routes; water and electricity safety; site facility inspection and maintenance
Facility	Activity facilities	Equipment failure; equipment quality; layout rationality; installation firmness; activity equipment inspection and maintenance
Management	Emergency rescue management	Emergency rescue organization configuration; emergency accident handling ability; emergency plan configuration; emergency accident response timeliness; emergency rescue personnel configuration; emergency rescue equipment configuration; safety training
Management	Medical support management	Scenic-area medical room configuration; medical staff configuration; medical staff level; emergency rescue medical equipment configuration
Environment	Natural environment	Rock collapse; adverse weather, including seasonal variation and rainstorms
Environment	Social environment	Epidemic disease; policy and regulation adjustment; public security in scenic areas

Table 3. Weight coefficients of primary and secondary indicators

Primary	*P*-Weight	Secondary Indicator	Local-W	Global-W
Personnel	0.2838	Tourists	0.3132	0.0889
		Specialist guides	0.3956	0.1123
		Project managers	0.2912	0.0827
Facility	0.3086	Site facilities	0.4654	0.1434
		Activity facilities	0.5346	0.1650
Management	0.2592	Emergency rescue management	0.5066	0.1313
		Medical support management	0.4934	0.1279
Environment	0.1484	Natural environment	0.6735	0.1000
		Social environment	0.3265	0.0485

3.3 Fuzzy comprehensive evaluation of the Shierbeihou case

After the indicator system and weights were determined, the Shierbeihou cave adventure tourism project was evaluated using questionnaire data and fuzzy comprehensive evaluation. The scale ranged from 1 (very low risk) to 5 (very high risk), with higher scores indicating higher perceived risk.

The overall perception-based fuzzy evaluation score was 2.3338. Using the predefined equal-interval scale, scores of 1.00-1.80 indicate very low risk, 1.81-2.60 low risk, 2.61-3.40 moderate risk, 3.41-4.20 high risk, and 4.21-5.00 very high risk. The case therefore fell in the low-risk category on this perception-based scale. This classification should not be interpreted as an objective estimate of accident probability or as evidence that high-consequence hazards are absent.

Personnel risk had the highest primary score (2.5567). The main elevated tertiary scores within this dimension were accidental injury (3.381), tourists' physical and mental health (3.317), specialist guides' emergency response awareness and ability (3.241), and project managers' safety training and education (3.326) (Table 4).

Facility risk scored 2.2967; site and activity facility inspection and maintenance were the facility items above 3.0 (3.188 and 3.114, respectively). Management risk scored 2.2847, with emergency rescue management (2.6307) higher than medical support management (1.9387); safety training (3.174) and response timeliness (3.004) were the management items above 3.0 (Table 4).

Environmental risk had the lowest primary score (2.0858). Although the natural and social environment scores were comparatively low, adverse weather, seasonal rainfall, public health events, and public security remain relevant to cave operations, consistent with research on cave and karst geotourism [22, 23].

Overall, the perception-based profile was low on the study scale but uneven, with elevated scores concentrated in specific personnel, facility-maintenance, and emergency-management indicators.

Table 4. Perception-based empirical evaluation results for the Shierbeihou Scenic Area

Primary Indicator	Primary Score	Secondary	Score	Priority Tertiary Risk Scores (≥3.000)
Personnel	2.5567	Tourists	2.3550	Accidental injury (3.381); physical and mental health (3.317)
		Specialist guides	2.6998	Emergency response awareness and ability (3.241)
		Project managers	2.6153	Safety training and education (3.326)
Facility	2.2967	Site facilities	2.3122	Site facility inspection and maintenance (3.188)
		Activity facilities	2.2822	Activity equipment inspection and maintenance (3.114)
Management	2.2847	Emergency rescue management	2.6307	Safety training (3.174); response timeliness (3.004)
		Medical support management	1.9387	None ≥ 3.000
Environment	2.0858	Natural environment	2.0798	None ≥ 3.000
		Social environment	2.0919	None ≥ 3.000

3.4 Priority risk points and management implications

Taken together, the AHP weights and empirical scores point to three operational priorities: facility maintenance, personnel preparedness, and emergency response. These priorities reflect the combination of relative importance and perceived risk, not objective accident probability.

Facility inspection and maintenance warrant particular attention because facility risk had the largest primary weight and both maintenance indicators exceeded 3.0. Routine inspection, maintenance records, and timely correction of detected defects are therefore central management actions.

For personnel-related risk, the elevated scores for accidental injury, tourist health, guide emergency response, and project-manager safety training indicate a need for pre-participation risk communication, guide preparedness, and staff training. Because the survey pooled tourists and practitioners, these findings should be read as mixed-stakeholder risk signals rather than direct measures of staff performance.

Emergency rescue remains important because safety training and response timeliness were elevated within the management dimension. In cave settings, constrained access can magnify the consequences of delayed response, supporting scenario-based training, clear responsibilities, and coordination between guides and rescue personnel.

Medical support and environmental scores were lower, but low perceived scores do not exclude low-frequency, high-consequence events. Medical readiness and environmental monitoring should therefore remain part of routine risk management [22, 23].

A low perception-based score does not imply the absence of safety concerns, particularly for low-frequency, high-consequence events.

4. CONCLUSIONS

This study developed and applied a project-level safety risk assessment framework for cave adventure tourism. The framework integrates personnel, facility, management, and environmental dimensions, with facility, personnel, and management risks carrying the greatest relative weight.

In the Shierbeihou case, the overall fuzzy evaluation score was 2.3338, corresponding to the low-risk category on the study's five-level perception-based scale. Elevated local scores remained for facility inspection and maintenance, accidental injury, tourist health, guide emergency response, project-manager safety training, response timeliness, and accident handling. The overall category should therefore be interpreted as a summary of perceived risk, not as an objective safety certification.

The study's contribution is the integration of Delphi-based indicator refinement, AHP weighting, and fuzzy comprehensive evaluation into a project-level pathway for identifying and prioritizing cave adventure tourism risks.

Several limitations should be considered. The empirical application involved one site, and the two-day on-site convenience recruitment of tourists and purposive recruitment of practitioners may limit representativeness. Most evidence came from questionnaires and expert judgment. Tourist and

practitioner responses were pooled, although some management-related indicators may be less observable to tourists; investigator explanations may also have influenced ratings. The same expert panel contributed to indicator development and weighting, so the study represents framework development and single-case application rather than independent validation. No objective accident, inspection, environmental monitoring, or rescue-performance records were available for triangulation. Future studies should use role-stratified samples, independent validation panels or sites, and objective operational data.

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NOMENCLATURE

B	Comprehensive membership vector
m	Number of indicators in the evaluation matrix
N_i	Total number of valid responses for indicator (i)
n_{ij}	Number of respondents selecting grade (j) for indicator (i)
R	Fuzzy evaluation matrix
r_{ij}	Membership degree of indicator (i) belonging to grade (j)
S	Final comprehensive evaluation score
V	Evaluation grade vector
W	AHP-derived weight vector

APPENDIX

1. Delphi expert panel

Eleven experts participated in all three anonymous Delphi rounds and in the subsequent weighting exercise. Eligibility required more than 5 years of relevant experience; academic experts held at least associate-professor appointments, scenic-area personnel held at least deputy-manager positions, and technical specialists held national mountain-rescue trainer certification.

Table A1. De-identified characteristics of the Delphi and weighting panel

Expert ID	Position/Title	Education	Relevant Experience (years)
E1	Deputy general manager	Bachelor's degree	15
E2	National mountain-rescue trainer	Postgraduate	18
E3	National mountain-rescue trainer	Postgraduate	21
E4	Project manager	Bachelor's degree	7
E5	General manager	Bachelor's degree	27
E6	Professor	Doctoral degree	13
E7	Associate professor	Postgraduate	7
E8	Associate professor	Doctoral degree	16
E9	Professor	Doctoral degree	31
E10	National mountain-rescue trainer	Postgraduate	12
E11	National mountain-rescue trainer	Postgraduate	21

2. Delphi participation and consensus

Table A2. Response and consensus across three Delphi rounds

Round	Completed/Invited	Response rate	Attrition	Primary W (p)	Secondary W (p)	Tertiary W (p)	Indicators (P/S/T)
1	11/11	100%	0	0.698 (0.002)	0.496 (0.001)	0.433 (<0.001)	4/10/53
2	11/11	100%	0	0.773 (<0.001)	0.623 (<0.001)	0.642 (<0.001)	4/9/46
3	11/11	100%	0	0.815 (<0.001)	0.695 (<0.001)	0.715 (<0.001)	4/9/46

3. Indicator changes after the first Delphi round

Table A3. Principal deletion, merging, relocation, and wording decisions

Initial Item	Decision	Final Item/Placement	Basis for Decision
Safety-training management (secondary)	Relocated	Safety training under emergency rescue management	Expert review of hierarchical fit
Equipment quantity	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Biological attack	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Mold infection in humid environments	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Poisonous plants	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Cave safety-knowledge explanation effectiveness	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Coordination ability	Deleted	-	Full-score ratio ≤ 0.19 and CV > 0.25
Personal equipment quality + public equipment quality	Merged	Equipment quality	Conceptual overlap
Emergency-action training effectiveness	Reworded	Safety training	Expert wording revision

4. Analytic hierarchy process (AHP) judgment matrices and consistency statistics

The tables below report the group-level AHP judgment matrices used in the weighting analysis. W denotes the local weight within each hierarchical group. All consistency ratios were below 0.10.

Table A4. Primary indicators A1-A4

A	A1	A2	A3	A4	W
A1	1.0000	0.9197	1.0949	1.9122	0.2838
A2	1.0873	1.0000	1.1905	2.0792	0.3086
A3	0.9133	0.8400	1.0000	1.7464	0.2592
A4	0.5229	0.4810	0.5726	1.0000	0.1484

Note: λmax = 4; CI = 0; CR = 0.0000

Table A5. Secondary indicators B1-B3 under personnel risk

A1-B	B1	B2	B3	W
B1	1.0000	0.7916	1.0753	0.3132
B2	1.2632	1.0000	1.3584	0.3956
B3	0.9300	0.7362	1.0000	0.2912

Note: λmax = 3; CI = 0; CR = 0.0000

Table A6. Secondary indicators B4-B5 under facility risk

A2-B	B4	B5	W
B4	1.0000	0.8706	0.4654
B5	1.1486	1.0000	0.5346

Note: λmax = 2; CI = 0; CR = 0.0000

Table A7. Secondary indicators B6-B7 under management risk

A3-B	B6	B7	W
B6	1.0000	1.0269	0.5066
B7	0.9738	1.0000	0.4934

Note: λmax = 2; CI = 0; CR = 0.0000

Table A8. Secondary indicators B8-B9 under environmental risk

A4-B	B8	B9	W
B8	1.0000	2.0629	0.6735
B9	0.4848	1.0000	0.3265

Note: λmax = 2; CI = 0; CR = 0.0000

Table A9. Tertiary indicators C1-C5 under tourists

B1-C	C1	C2	C3	C4	C5	W
C1	1.0000	0.9279	3.1768	1.0028	0.8524	0.2262
C2	1.0777	1.0000	3.4022	0.9947	0.9214	0.2396
C3	0.3148	0.2939	1.0000	0.9986	0.2706	0.0899
C4	0.9973	1.0054	1.0014	1.0000	1.0025	0.1882
C5	1.1732	1.0853	3.6949	0.9975	1.0000	0.2561

Note: λmax = 5.1889; CI = 0.0472; CR = 0.0422

Table A10. Tertiary indicators C6-C14 under specialist guides

B2-C	C6	C7	C8	C9	C10	C11	C12	C13	C14	W
C6	1.0000	1.1593	1.1542	1.4960	1.2914	2.0194	1.3237	1.1347	1.7541	0.1455
C7	0.8626	1.0000	0.9956	1.2904	1.1140	1.7420	1.1418	0.9788	1.5131	0.1255
C8	0.8664	1.0044	1.0000	1.2961	1.1189	1.7496	1.1469	0.9831	1.5198	0.1260
C9	0.6685	0.7749	0.7715	1.0000	0.8633	1.3499	0.8848	0.7585	1.1725	0.0972
C10	0.7743	0.8977	0.8937	1.1584	1.0000	1.5637	1.0250	0.8787	1.3583	0.1126
C11	0.4952	0.5741	0.5715	0.7408	0.6395	1.0000	0.6555	0.5619	0.8686	0.0720
C12	0.7555	0.8758	0.8719	1.1302	0.9756	1.5256	1.0000	0.8572	1.3251	0.1099
C13	0.8813	1.0216	1.0172	1.3184	1.1381	1.7797	1.1666	1.0000	1.5458	0.1282
C14	0.5701	0.6609	0.6580	0.8529	0.7362	1.1513	0.7546	0.6469	1.0000	0.0829

Note: λmax = 9; CI = 0; CR = 0.0000

Table A11. Tertiary indicators C15-C20 under project managers

B3-C	C15	C16	C17	C18	C19	C20	W
C15	1.0000	1.8864	1.0794	1.7987	1.6728	0.9788	0.2159
C16	0.5301	1.0000	0.5722	0.9535	0.8868	0.5189	0.1144
C17	0.9264	1.7476	1.0000	1.6664	1.5498	0.9068	0.2000
C18	0.5559	1.0487	0.6001	1.0000	0.9300	0.5442	0.1200
C19	0.5978	1.1277	0.6453	1.0753	1.0000	0.5851	0.1291
C20	1.0216	1.9272	1.1027	1.8377	1.7090	1.0000	0.2206

Note: λmax = 6; CI = 0; CR = 0.0000

Table A12. Tertiary indicators C21-C25 under site facilities

B4-C	C21	C22	C23	C24	C25	W
C21	1.0000	1.0215	2.0118	2.7969	0.8838	0.2522
C22	0.9789	1.0000	1.9694	2.7380	0.8652	0.2469
C23	0.4971	0.5078	1.0000	1.3902	0.4393	0.1254
C24	0.3575	0.3652	0.7193	1.0000	0.3160	0.0902
C25	1.1315	1.1558	2.2763	3.1647	1.0000	0.2854

Note: λmax = 5; CI = 0; CR = 0.0000

Table A13. Tertiary indicators C26-C30 under activity facilities

B5-C	C26	C27	C28	C29	C30	W
C26	1.0000	0.9684	2.3177	2.8436	0.9566	0.259
C27	1.0326	1.0000	2.3934	2.9364	0.9878	0.2674
C28	0.4315	0.4178	1.0000	1.2269	0.4127	0.1117
C29	0.3517	0.3406	0.8151	1.0000	0.3364	0.0911
C30	1.0454	1.0123	2.4229	2.9726	1.0000	0.2707

Note: λmax = 5; CI = 0; CR = 0.0000

Table A14. Tertiary indicators C31-C37 under emergency rescue management

B6-C	C31	C32	C33	C34	C35	C36	C37	W
C31	1.0000	0.9357	1.7239	0.9253	1.0252	1.0503	0.8859	0.1474
C32	1.0687	1.0000	1.8421	0.9878	1.1075	1.1213	0.947	0.1577
C33	0.5801	0.5429	1.0000	0.5361	0.6173	0.6085	0.5138	0.0859
C34	1.0807	1.0123	1.8655	1.0000	1.1207	1.1343	0.9589	0.1596
C35	0.9754	0.9029	1.6199	0.8923	1.0000	0.9996	0.8645	0.1421
C36	0.9521	0.8919	1.6434	0.8816	1.0004	1.0000	0.8435	0.1409
C37	1.1288	1.0560	1.9462	1.0429	1.1567	1.1855	1.0000	0.1663

Note: λmax = 7; CI = 0; CR = 0.0000

Table A15. Tertiary indicators C38-C41 under medical support management

B7-C	C38	C39	C40	C41	W
C38	1.0000	1.2244	1.4772	1.0867	0.2930
C39	0.8167	1.0000	1.3396	0.9559	0.2503
C40	0.6770	0.7465	1.0000	0.7923	0.1969
C41	0.9202	1.0461	1.2621	1.0000	0.2598

Note: λmax = 4.0021; CI = 0.0007; CR = 0.0008

Table A16. Tertiary indicators C42-C43 under natural environment

B8-C	C42	C43	W
C42	1.0000	0.5020	0.3342
C43	1.9920	1.0000	0.6658

Note: λmax = 2; CI = 0; CR = 0.0000

Table A17. Tertiary indicators C44-C46 under social environment

B9-C	C44	C45	C46	W
C44	1.0000	2.1098	3.9157	0.5783
C45	0.4740	1.0000	1.8559	0.2741
C46	0.2554	0.5388	1.0000	0.1477

Note: λmax = 3; CI = 0; CR = 0.0000

5. Local and global weights of the 46 tertiary indicators

Table A18. Local and global weights of tertiary indicators

Code	Primary	Secondary	Tertiary Indicator	Local W	Global W
C1	Personnel	Tourists	Safety awareness	0.2262	0.0201
C2	Personnel	Tourists	Accidental injury	0.2396	0.0213
C3	Personnel	Tourists	Self-management	0.0899	0.0080
C4	Personnel	Tourists	Learning ability	0.1882	0.0167
C5	Personnel	Tourists	Physical and mental health	0.2561	0.0228
C6	Personnel	Specialist guides	Safety awareness	0.1455	0.0163
C7	Personnel	Specialist guides	Theoretical and technical competence	0.1255	0.0141
C8	Personnel	Specialist guides	Working condition	0.1260	0.0141
C9	Personnel	Specialist guides	Work experience	0.0972	0.0109
C10	Personnel	Specialist guides	Emergency response awareness and ability	0.1126	0.0126
C11	Personnel	Specialist guides	Psychological quality	0.0720	0.0081
C12	Personnel	Specialist guides	Professional qualification	0.1099	0.0123
C13	Personnel	Specialist guides	Routine inspection	0.1282	0.0144
C14	Personnel	Specialist guides	Professional ethics	0.0829	0.0093
C15	Personnel	Project managers	Safety training and education	0.2159	0.0178
C16	Personnel	Project managers	Management ability	0.1144	0.0095
C17	Personnel	Project managers	Safety awareness	0.2000	0.0165
C18	Personnel	Project managers	Professional ethics	0.1200	0.0099
C19	Personnel	Project managers	Qualification certification	0.1291	0.0107
C20	Personnel	Project managers	Emergency response awareness and ability	0.2206	0.0182
C21	Facility	Site facilities	Safety warning signs in caves	0.2522	0.0362
C22	Facility	Site facilities	Safety protection facilities	0.2469	0.0355
C23	Facility	Site facilities	Congestion of experience routes	0.1254	0.0180
C24	Facility	Site facilities	Water and electricity safety	0.0902	0.0130
C25	Facility	Site facilities	Site facility inspection and maintenance	0.2854	0.0410
C26	Facility	Activity facilities	Equipment failure	0.2590	0.0427
C27	Facility	Activity facilities	Equipment quality	0.2674	0.0441
C28	Facility	Activity facilities	Layout rationality	0.1117	0.0184
C29	Facility	Activity facilities	Installation firmness	0.0911	0.0150
C30	Facility	Activity facilities	Activity equipment inspection and maintenance	0.2707	0.0447
C31	Management	Emergency rescue management	Emergency rescue organization configuration	0.1474	0.0194
C32	Management	Emergency rescue management	Emergency accident handling ability	0.1577	0.0207

C33	Management	Emergency rescue management	Emergency plan configuration	0.0859	0.0113
C34	Management	Emergency rescue management	Emergency accident response timeliness	0.1596	0.0210
C35	Management	Emergency rescue management	Emergency rescue personnel configuration	0.1421	0.0187
C36	Management	Emergency rescue management	Emergency rescue equipment configuration	0.1409	0.0185
C37	Management	Emergency rescue management	Safety training	0.1663	0.0218
C38	Management	Medical support management	Scenic-area medical room configuration	0.2930	0.0375
C39	Management	Medical support management	Medical staff configuration	0.2503	0.0320
C40	Management	Medical support management	Medical staff level	0.1969	0.0252
C41	Management	Medical support management	Emergency rescue medical equipment configuration	0.2598	0.0332
C42	Environment	Natural environment	Rock collapse	0.3342	0.0334
C43	Environment	Natural environment	Adverse weather, including seasonal variation and rainstorms	0.6658	0.0665
C44	Environment	Social environment	Epidemic disease	0.5783	0.0280
C45	Environment	Social environment	Policy and regulation adjustment	0.2741	0.0133
C46	Environment	Social environment	Public security in scenic areas	0.1477	0.0072

6. Survey recruitment by time period

Table A19. Returned questionnaires by survey day and operating-time block

Date	Time Block	Returned Questionnaires
5 April 2026	08:30-10:30	14
5 April 2026	10:30-12:30	21
5 April 2026	14:30-16:30	122
5 April 2026	16:30-18:30	98
6 April 2026	08:30-10:30	10
6 April 2026	10:30-12:30	11
6 April 2026	14:30-16:30	131
6 April 2026	16:30-18:30	51
Total		458

7. Respondent characteristics

Table A20. Characteristics of the 447 valid respondents

Characteristic	Category	n (%)
Sex	Male	201 (45.0%)
Sex	Female	246 (55.0%)
Age	24 years or younger	159 (35.6%)
Age	25-35 years	246 (55.0%)
Age	36-45 years	33 (7.4%)
Age	46 years or older	9 (2.0%)
Occupation	Freelance/self-employed	34 (7.6%)
Occupation	Student	171 (38.3%)
Occupation	Enterprise/institution employee	210 (47.0%)
Occupation	Civil servant	11 (2.5%)
Occupation	Military	10 (2.2%)
Occupation	Retired	11 (2.5%)
Origin	Within Guizhou Province	98 (21.9%)
Origin	Outside Guizhou Province	338 (75.6%)
Origin	International	11 (2.5%)