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Comprehensive risk management of health, safety and environment for social emergency rescue organization

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ABSTRACT

During the rescue and relief work of social emergency rescue organizations, the rescue team members face significant responsibilities and risks. Social rescue organizations need to improve funding, available equipment and other aspects compared with professional emergency rescue organizations. Moreover, the development of rescue levels among emergency rescue organizations is unbalanced, and rescue teams'' comprehensive quality and skills are uneven. To understand the safety risks of these organizations before the implementation of rescue and relief tasks, the task situation and its characteristics must be assessed timely, and safety must be ensured under the premise of efficient completion of the rescue missions. Based on the theory of safety system engineering and health, safety, and environment risk management, a risk management model is established to achieve a closed-loop risk management. The risk factors in rescue and relief tasks of social rescue organizations were identified, and a health, safety and environment risk assessment index system and grading standard were established. A gray cloud model was applied for the evaluation method, the problems of information randomness, risk-level boundary fuzziness and randomness of the evaluation index data were effectively solved. Subsequently, a risk hierarchical early warning and control strategies were proposed to allocate emergency resources rationally. The proposed method was verified and found to have universal applicability and strong practicability.

1. Introduction

Social emergency rescue has gradually become essential to the emergency force system, which assumes an irreplaceable role in preparing for and responding to emergencies. It has the advantages of eliminating the bureaucratic predicament of government agencies, compensating for the shortage of professional emergency rescue forces, improving the perception of the environment, and ability to adapt to complex situations [1]. In June 2022, more than 1700 China social emergency organizations were registered in civil affairs and other departments with 40,000 personnel. Whenever disaster strikes, they respond immediately. According to incomplete statistics, from 2018 to 2020, approximately 300,000 people participated in rescue and relief, and approximately 1.8 million people participated in voluntary emergency services [2]. In the process of rescue and relief, casualties of social emergency rescue personnel often occur. From November 23 to December 1, 2021, three social emergency rescue team members died in the Zhanghe River in eight days for the same task. As a result, social emergency rescue organizations face serious risks and challenges. First, the primary disasters continue to expand and develop, and second, the coupling of various risks leads to escalation of events, increasing the complexity and

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difficulty of rescue. Moreover, compared with professional emergency rescue forces, social rescue organizations need to improve funding and available equipment [3]. Furthermore, the training programs of emergency rescue organizations in regions are different, the development of rescue levels among emergency rescue organizations is unbalanced, and rescue teams' comprehensive quality and skills are uneven. While helping others, rescue team members face huge responsibilities and risks [4,5], which will significantly affect the enthusiasm of social emergency rescue organizations to participate in public welfare rescue.

Risk assessment is recognized as a critical systematic tool for safety management. In recent years, quantitative and qualitative risk assessment methods have been widely applied in aviation, mining, construction, offshore drilling, and other fields [6–9]. Vishnu [10] believed risk assessment has become the standard term for health, safety, and environmental management (HSE) over the past decades. Risk assessment is the first step towards systematic and successful occupational HSE management. Regarding HSE risk management, Ak et al. [11] conducted occupational health, safety, and environmental risk assessment on the textile production industry through the Bayesian Vikor method. The research results help guide decision-makers and authorities in the textile production industry to pay attention to priority hazards and related risks in the risk management cycle's risk control steps. Rezaian and Jozi [12] evaluated refinery activities' health, safety, and environmental risks based on the multi-criteria decision-making method and obtained the most important factors affecting refinery risks and the most critical natural consequences. Yang et al. [13] established the overall Occupation HSE risk of nuclear power plant construction projects from the perspective of risk identification and risk assessment. The research results showed that this method helped reduce the risk level of occupation HSE and protect the occupational health and safety of workers and the environment during the NPP construction project. Mustafa et al. [14] integrated language FMEA, fuzzy reasoning system, and fuzzy DEA to analyze health, safety, and environmental risks in the chemical industry.

From the perspective of emergency rescue, Rake [15] believed that risk assessment is a judicious decision-making process in rescue operations. Currently, scholars are studying the risk assessment of accidents or disasters and their rescue operations. He and Zhai [16] considered the disaster risk assessment provided a basis for the rapid and effective preparation of rescue and relief programs. Thus, a reasonable allocation of rescue personnel and material resources was realized. Vafaeinezhad et al. [17] established a risk management and control model for earthquake life detection rescue teams from the perspective of time and space, which is helpful in solving the multidimensional problem of risk management. Selman et al. [18] set up procedures for confined space rescue to reduce the risk to rescuers. Wang et al. [19] identified the main risk factors for aviation emergency rescue from the perspectives of rescue teams, professional equipment, infrastructure equipment, organizational support, and disaster situation. A comprehensive multi-attribute group decision-making method was used to conduct a risk assessment of the aviation emergency rescue. Xiong et al. [20] evaluated the risks of maritime battlefield search and rescue vessels based on a back propagation (BP) neural network by analyzing the risk, vulnerability, and resilience and comprehensively considering the marine environmental factors, ship conditions, enemy threat, crew capability, and external rescue. Lunde and Nja [21] simulated the risks associated with road rescue caused by avalanches in Norway and the overall performance of rescue services using Bayesian networks. The results showed that attention must be paid to factors allowing rescuers to maintain control of their own safety, improve risk awareness, and set aside time for the required avalanche risk assessment and management. Li et al. [22] took an underground gas explosion in a coal mine as an example and combined a generalized regression neural network with computational fluid dynamics to evaluate the exposure degree of the explosion risk of rescue workers to provide support for emergency rescue decision-making. However, the study on a comprehensive HSE risk assessment of rescue members is limited.

This study proposes a comprehensive HSE risk assessment framework and quantitatively evaluates the risks faced by rescue and relief personnel, in terms of equipment and facilities, organization and management, environmental conditions, tasks, and other aspects. According to the risk value, hierarchical risk early-warning and control strategies are established, emergency resources are rationally allocated to realize closed-loop risk management.

2. Methods

2.1. Methodology for identification of risk element

Social emergency rescue organizations take huge risks when participating in rescue and relief. From a health, safety, and environmental point of view, it includes the physical and psychological problems of their personnel, mistakes of the command personnel, actions of personnel not following the rules, non-scientific or lenient daily training and practice, and failure of equipment and facilities; the continuous evolution and expansion of accidents and disasters, and the disturbance of local natural and social environmental conditions. The system safety factors are widely accepted and include man, machine, environment, management, and mission [23,24]. Considering the characteristics of the social emergency rescue and relief, a risk assessment index system was developed based on five aspects: personnel, equipment and facilities, management, environment, and task.

The methods for establishing the risk assessment index system are as follows: First, according to the five elements of risk factor identification and based on the relevant literatures [25–30], the various risk factors that social emergency organizations may encounter in implementing rescue and relief tasks are theoretically defined. Second, in-depth investigation and research on the relevant departments of social emergency rescue organizations are conducted, and discussions are held to understand the difficulties in actual rescue and relief based on historical data records. Subsequently, an evaluation index system is preliminarily established, and questionnaires are distributed to experts engaged in scientific research and teaching in this field for their opinions. After several rounds of modifications, the index system and classification standards are revised and improved. Finally, an index system of safety risk assessment for the rescue and relief tasks of social emergency rescue organizations are established.

2.2. Methodology for risk quantification

Since the qualitative indicators can not directly express the detailed numerical values, the evaluation set of qualitative indicators is referred to the Opinions of the Office of the State Council Safety Commission on Building a Double Prevention Mechanism by Implementing the Work Guidelines on Major Accidents (No. 11, 2016) of the Office of the Safety Commission. The evaluation criteria of the evaluation indicators were divided into four levels, with the risk ranking from highest to lowest as significant, considerable, general, and low. The higher the risk, the greater the risk level. Specifically, the quantification of index is classified into three categories. The first is the quality and ability of personnel and the state of equipment and facilities in performing activities. The distribution range is statistics according to the historical data of each personnel training and performance and the records of equipment and facilities. The second is the descriptive index of the reasonable personnel and equipment implementation degree. Rescue organizations' relevant internal norms and equipment standards are the basis for division into four levels. They corresponded to low, general, considerable, and significant risks. The third is the reality of the implementation of the task, and such indicators are highly variable. The corresponding number of dispatched and task plans are matched based on the comprehensive consideration of the natural environment and social situation. The quantitative classification of indicators is determined after reviewing the relevant summary report and expert consultation. Generally, the quantitative classification of qualitative indicators results from expert evaluation and data analysis of historical cases.

2.3. Methods for risk assessment

(1) Method for index weight calculation

In this study, index weights are obtained using the G1 weighting method. G1 subjective weighting is based on an analytic hierarchy process, omitting the process of consistency testing, which makes the evaluation process simpler and more convenient for obtaining the weight coefficients of evaluation indicators [31]. The steps for calculating the G1 subjective weighting are as follows.

Step 1. Rank the evaluation indicators according to their importance and determine the order relationship among them.

For a criterion layer (target layer) of evaluation indicators $x_1, x_j, \ldots, x_n$, if the importance of x_i is greater than x_j, then $x_i^* > x_j^*$, according to which the order relationship between all indices is determined.

Step 2. Calculate the relative importance of each adjacent index.

$$\frac{w_{j-1}}{w_j} = r_j j = n, n-1, n-2, \ldots, 3, 2 \tag{1}$$

where w_{j-1} and w_j represent the weight coefficients of x_{j-1}^* and x_j^*, respectively, after ranking the evaluation indices.

Here, r_j denotes the relative importance of the $j-1$ and j indices, as presented in Table 1.

Step 3. Calculate the weight coefficient w_j^*.

First, the weight of the nth evaluation index x_n^* after ranking is calculated.

$$\begin{cases} w_n^* = \dfrac{1}{\left(1 + \sum\limits_{j=2}^{n} \prod_{k=j}^{n} r_k\right)} \\ w_{n-1}^* = r_j w_j^*, j = n, n-1, n-2, \ldots, 3, 2 \end{cases} \tag{2}$$

Step 4. Reverse adjust the weight coefficient w_{sj} of the original index according to w_j^*.

Step 5. Calculate the average value of different weight coefficients obtained from experts to obtain the final weight.

$$w_{oj} = \frac{\sum\limits_{p=1}^{L} w_{pj}}{L} \tag{3}$$

Table 1
Value reference of r_j.

Importance score	Description of the degree of importance between indicators
1.0	Equally important
1.2	Slightly important
1.4	Obviously important
1.6	Strongly important
1.8	Extremely important

where L is the number of experts, and w_{pj} is the weight value calculated by different experts for the same indicator.

(2) Method for Evaluation model

Social emergency organization rescue and relief is a complex system. There are many uncertain factors, including the determination of the risk-level boundary, as well as the randomness and uncertainty in the data collection process. Therefore, this study combines the gray theory with the cloud model to make the evaluation results closer to reality. The application of the gray cloud model in all types of risk assessments is relatively advanced, so it can comprehensively and systematically describe the internal correlation among evaluation index systems, and the incompleteness, fuzziness, and randomness of decision information can be addressed [32, 33].

The gray number is the most fundamental concept in the gray system theory. Usually, only a range of values is known, but the exact value is unknown. Some gray numbers can find a white number as its "representative" gray number; this white number is the corresponding gray number whitening value. Therefore, the whitening weight function is used to describe the extent of preference of a gray number to different values within its range [34]. The cloud model is a comprehensive evaluation model to use to solve the ambiguity and randomness of a system [35]. It is defined as follows: Let U be a quantitative domain represented by numerical values and C be a qualitative concept of U. If quantitative values $c \in U$, and c is a random qualitative C concept implementation, any element for any U expression of the concept of gray winterization weight has a stable tendency of random numbers, say c gray cloud winterization weight for U. Its distribution in U, called the winterization weight function of gray cloud, is referred to as the gray cloud. In summary, the gray system solves information incompleteness, whereas the cloud model solves fuzziness and randomness. By combining the two, the gray cloud model comprehensively addresses information incompleteness, randomness, and uncertainty in decision-making. The curve of the gray cloud model conforms to a normal distribution. In the data range of disaster relief assessment indices of social emergency rescue organizations, the variable values are continuous and normally distributed. Therefore, the risk assessment index data of social emergency rescue organizations suit the gray cloud model.

(1) Calculation process of a gray cloud model

The gray cloud model is characterized by the expected value E_x, left and right boundaries (L_x, R_x), entropy E_n, and super-entropy H_e. Among them

$$E_x = \frac{L_x + R_x}{2} \tag{4}$$

$$E_n = \frac{R_x - L_x}{6} \tag{5}$$

$$H_e = \frac{E_n}{q} \tag{6}$$

where L_x and R_x respectively represent the left and right boundaries of the gray cloud model and the numerical range of the gray concept in its discussed field. q specifies a constant.

The mathematical expectation curve of a typical gray cloud satisfies the following:

$$L = exp\left\{ -\frac{(x - Ex)^2}{2\left(\frac{Rx - Lx}{6}\right)^2} \right\} \tag{7}$$

Any cloud drop of the regular gray cloud model graph satisfies the following:

$$f_i = exp\left\{ -\frac{(x_i' - Ex)^2}{2(x_i')^2} \right\} \tag{8}$$

If the following formula is satisfied, it is called the standard gray cloud whitening weight model with a reasonable measure:

$$fi(x) = \begin{cases} \exp\left[-\frac{(x_i' - Ex)^2}{2(x_i')^2} \right], x \in [L_X, R_X] \\ 0, x \notin [L_X, R_X] \end{cases} \tag{9}$$

If the following formula is satisfied, it is called the standard gray cloud whitening weight model with an upper limit measure:

$$fi(x)=\begin{cases} 0, x \notin [L_X, R_X] \\ \exp\left[-\frac{(x_i^{'}-Ex)^2}{2(x_i^{'})^2}\right], x \notin [L_X, Ex] \\ 1, x \in [L_X, R_X] \end{cases} \tag{10}$$

If the following formula is satisfied, it is called the standard gray cloud whitening weight model with a lower limit measure:

$$fi(x)=\begin{cases} 1, x \in [L_X, Ex] \\ \exp\left[-\frac{(x_i^{'}-Ex)^2}{2(x_i^{'})^2}\right], x \notin [L_X, Ex] \\ 0, x \notin [L_X, R_X] \end{cases} \tag{11}$$

The standard gray cloud generation algorithm steps are as follows.

1) Generate a standard random number $x_i^{'}$ with E_n as an expectation and H_e as a standard deviation;
2) Generate a standard random number x_i with E_x as an expectation and X_i as a standard deviation;
3) Eq. (7) is used to calculate the whitening weight of a typical gray cloud, where $(x_i, fi(x))$ is the generated gray cloud droplet;
4) Repeat the first three steps to obtain the desired cloud drops;
5) The above regular gray cloud model generation algorithm produces an image with $E_x = 40$, $E_n = 8$, $H_e = 0.5$, and 5000 cloud drops, as shown in Fig. 1.

(2) Clustering of gray cloud model

The clustering calculation process of the gray cloud model is as follows.

Step1. Take the average gray cloud whitening weight $f_j^k(x)$ calculated h times, and normalize the whitening weight of each level of the same index.

$$f_j^k(x)=\frac{f_{j1}^k(x)+f_{j2}^k(x)+\ldots\ldots+f_{jh}^k(x)}{h} \tag{12}$$

$$\mu_j^k(x)=\frac{f_j^k(x)}{\sum_{k=1}^{n} f_j^k(x)} \tag{13}$$

Here, $f_j^k(x)$ is the whitening weight for each gray category of each indicator.

Step 2. Calculate the clustering coefficient. It is assumed that the comprehensive clustering coefficient of gray k is σ_k when the social emergency rescue organization executes rescue and relief tasks, and the clustering coefficient set is denoted as $[\sigma_1, \sigma_2, \sigma_3, \sigma_4]$:

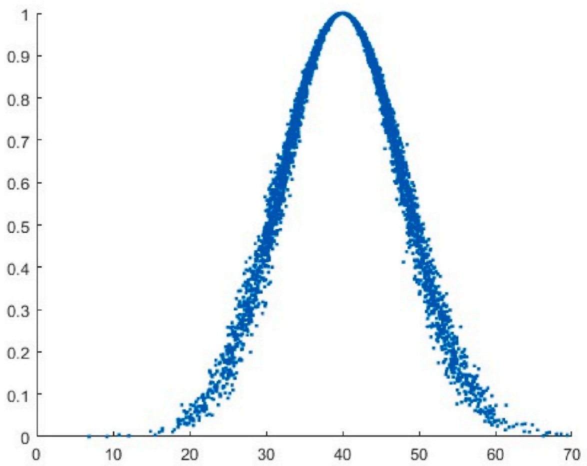


Fig. 1. Schematic diagram of the gray cloud model.

$$\sigma_k = \sum_{i=1}^{n} \mu_j^k(x) * w_j \tag{14}$$

where, k is the risk level of rescue and disaster relief for social rescue organizations and w_j is the weight of each indicator.

Step 3. Determine the evaluation results based on the principle of maximum membership degree.

$$Max\{\ \sigma_k\} = \sigma_k\ (1 \le \mathrm{k} \le 4) \tag{15}$$

2.4. Methodology for risk alert and control policy

According to GB 2893–2001 "Safety colors" GB/T 2893.1–2004 "Graphic symbols safety colors and safety signs Part 1-Design Principles for Safety Signs in workplaces and public areas" and GB/T 4025–2003 "Human-machine interface logo basic and safety rules according to the relevant guidelines of Coding Rules for Indicators and Operators", the HSE comprehensive safety risk warning of social emergency rescue organizations is divided into four warning levels according to the actual needs of emergency rescue organizations. The warning colors are "I" (extremely severe), "II" (severe), "III" (relatively severe), and "IV" (general). The corresponding warning colors are "red", "orange", "yellow" and "blue".

1) Red alert: Risk control should be carried out immediately if there is an obvious danger sign or an intolerable risk;
2) Orange alert: High risk, principal risk, must develop measures to control management;
3) Yellow alert: Moderate (significant) danger requiring control and rectification;
4) Blue alert: Slightly or mildly dangerous, requiring attention or negligible, acceptable.

3. Results and discussion

3.1. Results from identification of risk elements of social emergency rescue organization

Social emergency rescue organizations rescue and disaster relief risk factors include the following five aspects.

(1) Personnel

Personnel is the most dynamic and flexible factor affecting the risk of social emergency rescue organizations. The state, quality, and ability of personnel are the keys to ensuring the success of a task. The risks of rescue and relief personnel mainly emanate from physiological and psychological factors, which primarily refer to whether the physical condition and mental state of personnel are good and whether there are physiological or psychological factors affecting the implementation of rescue and relief tasks. The factors to be considered include the excellent rating of personnel physical examination results and psychological evaluation scores are good or higher in the past year. The second is the quality of personnel: whether the technical level of rescue and relief personnel is excellent, whether they have received professional training, and whether they can deal with emergencies. Only personnel with excellent and good ratings of recent physical fitness training assessment and passing rates of emergency disposal assessment and self-rescue and mutual rescue skills assessment in the past year should be considered. The stronger the physical and psychological conditions, quality ability, practical experience in rescue and relief, emergency ability, and other aspects of rescue and relief personnel, the lower the risk they may face in the execution of rescue and relief tasks. Rescue and relief need to bear substantial psychological pressure, such as seeing the tragic situation of victims and dealing with the aftermath of a disaster, which can lead to psychological problems and post-traumatic stress disorders. Therefore, it is imperative to understand timely the risk-prevention dynamics of disaster relief personnel.

(2) Equipment and facilities

Equipment and facilities are fundamental guarantees for the implementation of rescue and relief, and they are the keys to ensure the successful completion of a task. Equipment and facilities include general and special emergency equipment and related mechanized vehicles used during emergency rescue operations. The risks of equipment and facilities originate from two aspects: 1) faulty equipment and facilities or unsafe support system; 2) interference of external factors, including inappropriate operation or lack of a timely maintenance , which reduces the performance. In rescue and relief, it is necessary to consider whether the performance of all related equipment and facilities can meet the task requirements, as well as the impact on all task activities, especially the impact of the failure rate of equipment and tools on safe use. The factors to consider include universal emergency equipment, specialized emergency equipment, and mechanized rescue equipment as well as the rationality, completeness, and failure rate of the equipment. Therefore, before performing a task, factors, such as the support conditions, reliability, maintenance, and storage measures of equipment and facilities, should be comprehensively considered to guarantee technical performance and effective use.

(3) Management

Table 2
The safety risk assessment indexes and grading standards for rescue and relief tasks of social emergency rescue organizations.

First-order index	Secondary index	Three-level index	Level one significant risk	Level two considerable risk	Level three general risk	Level four low risk
Personnel	Physiological status	X_{11} Excellent rating of personnel physical examination results	0%–30 %	20%–50 %	40%–80 %	60%–100 %
	Psychologic status	X_{12} Psychological evaluation scores are good or higher in the past year	0%–60 %	40%–85 %	80%–95 %	90%–100 %
	Quality and ability	X_{13} Excellent and good ratings of physical fitness training in the past year	0%–30 %	20%–45 %	40%–75 %	50%–100 %
		X_{14} Passing rate of personnel emergency disposal assessment in the past year	0%–70 %	60%–85 %	80%–95 %	90%–100 %
		X_{15} Passing rate of self-rescue and mutual rescue skills assessment in the past year	0%–70 %	60%–85 %	80%–95 %	90%–100 %
Equipment and facilities	Universal emergency equipment (personal protection, alarm, communication equipment, etc.)	X_{21} The rationality of general emergency equipment	0–75	70–85	80–95	90–100
		X_{22} General emergency equipment completeness	0–75	70–85	80–95	90–100
		X_{23} General emergency equipment condition	0–75	70–85	80–95	90–100
		X_{24} Failure rate of universal emergency equipment	10%–100 %	5%–45 %	3%–7.5 %	0%–4%
	Specialized emergency equipment (Fire extinguishing equipment, dangerous goods leakage control, exceptional communication, medical treatment, electric emergency)	X_{25} Special professional emergency equipment is reasonably equipped	0–75	70–85	80–95	90–100
		X_{26} Failure rate of special specialized emergency equipment	10%–100 %	5%–45 %	3%–7.5 %	0%–4%
	Mechanized rescue equipment (vehicles, excavators, cranes and other large machinery, food support vehicles, etc.)	X_{27} Mechanized rescue equipment periodic maintenance rate	0%–85 %	80%–92.5 %	90%–97.5 %	95%–100 %
		X_{28} Mechanical rescue equipment failure rate	10%–100 %	5%–45 %	3%–7.5 %	0%–4%
Management	Personnel group management	X_{31} The rationality of personnel formation	0–75	70–85	80–95	90–100
	Safety management	X_{32} Special analysis of the safety situation before the mission	0–75	70–85	80–95	90–100
		X_{33} Safety education of personnel before performing tasks	0–75	70–85	80–95	90–100
	Logistics management	X_{34} Adequacy of food supplies	0–75	70–85	80–95	90–100
		X_{35} Adequacy of fuel supplies	0–75	70–85	80–95	90–100
		X_{36} The perfection of medical first aid guarantee	0–75	70–85	80–95	90–100
		X_{37} The perfection of the alert system	0–75	70–85	80–95	90–100
	Multi-party coordination	X_{38} Coordinate with local government, social groups, international organizations and other parties	0–75	70–85	80–95	90–100
Environment	Natural environment	X_{41} The possibility of natural disasters (such as rock falls and debris flows) occurring around the rescue site	70–100	50–87.5	30–60	0–45
	Social environment	X_{42} Local social security situation	0–75	70–85	80–95	90–100
Task	Start-up scale	X_{51} Start-up number	5000–100000	1000–7500	200–2500	0–400
		X_{52} Number of vehicles deployed	30–40	20–30	10–20	0–10
		X_{53} Estimate the task duration (day)	30–45	15–37.5	7–22.5	0–11
	Task difficulty	X_{54} Task intensity	90–100	80–95	70–85	0–75
	Task situation	X_{55} Task situation judgment	0–75	70–85	80–95	90–100
	Task plan	X_{56} Clarity of task plan content	0–75	70–85	80–95	90–100

According to the calculation steps of the gray cloud model, taking “excellent rating of recent personnel physical examination results, psychological evaluation scores are good or higher psychological evaluation scores in the past year, excellent and good ratings of personnel physical fitness training assessment in the past year, and passing rate of personnel emergency disposal assessment in the past year” as examples, the status is divided according to the levels of each risk assessment index. Eqs. (4)–(6) are used to calculate the digital characteristics of the gray cloud models of different levels, as presented in Table 3.

Management measures are essential contents that must be addressed to reduce the risk of rescue and relief. Comprehensive management measures can be used to arrange and coordinate various complex factors. Management is reflected in the aspects of personnel, safety, logistics, coordination with social organizations, etc. The risks of organizational safety management originate from the following. First, whether various management systems are comprehensive, and whether the responsibilities, organization, organizational structure, organizational leadership, command, and control of each organization are clear and consistent with the actual situation. Second is the implementation of the system in the processes of supervision, inspection, and timely rectification of existing problems. Therefore, the rationality of personnel formation, special analysis of the safety situation before the mission, safety education of personnel before performing tasks, adequacy of food and fuel supplies, perfection of medical first aid guarantee and alert system, and coordination with local governments, social groups, international organizations, and other parties are essential factors to be considered in management.

(4) Environment

The task environment consists of both natural and social factors. Social emergency rescue members face unfamiliar areas and perform complex rescue and relief tasks. The environment varies, and there are many uncertainties. For example, in earthquake relief, the earthquake will result in landslides, aftershocks, debris flow, and other secondary disasters, severely impacting not only the power, communication, water supply, and other security conditions but also causing psychological damage to personnel. When there is misunderstanding or poor communication between rescue members and the public, the actions of social emergency rescue forces may be questioned and criticized, which is a risk to public opinion regarding rescue and relief missions. Therefore, the risk of the task environment emanates from the impact of the natural environment, such as mountain floods, collapses, landslides, debris flows, and lightning, as well as the impact of local customs, public security, and other social situations on task safety.

(5) Task

The mission depends on the personnel, environment, equipment, and management. Its success and safety are fundamental goals of risk management. Social emergency organizations perform rescue and relief tasks in various situations. Before implementing the task, a detailed understanding of the purpose, significance, and implementation process requirements of the task; nature and characteristics of the task; and scale level, joint degree, and operational difficulty intensity obtained from the overall comprehension of the degree of risk is required in advance to assess the possible risk factors. Therefore, determining the number of personnel and vehicles to be deployed , estimating the task duration and intensity, evaluating the task situation, and clarifying the task plan content are necessary.

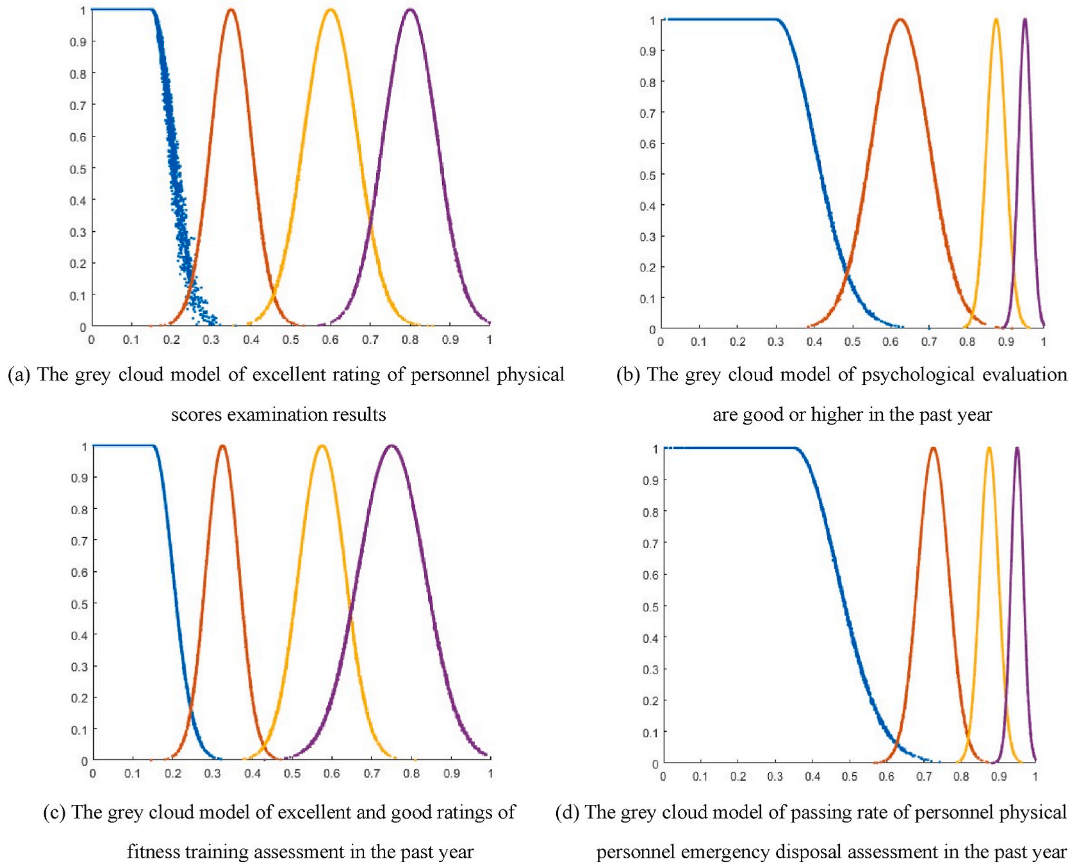
3.2. Results for risk assessment indicators and grading standards

The index system consisted of three levels comprising 29 tertiary indicators. The safety risk assessment indices and grading standards for the rescue and relief tasks of social emergency rescue organizations are listed in Table 2.

Fig. 2 (a)-(d) illustrates the corresponding cloud images. Each cloud map consists of four “gray clouds”, the four-color curves from left to right correspond to thefour gray categories of indicators. The gray cloud diagram is the most intuitive representation of the cloud model. As can be seen from the figure, each cloud in the cloud map is “atomized” with the expectation as the center. The farther away from the expectation, the more pronounced the “atomization” effect. The “atomization” effect is worse when closer to the cloud expectation. The “atomization” effect shows that when the horizontal axis values are the same, the vertical axis values are affected by randomness, which indicates the randomness reflected in the model. Different clouds may cross, and adjacent clouds must cross each

Table 3
Digital characteristics of gray cloud models at each level of evaluation indexes.

Evaluation index	First order	Second level	Tertiary	Quaternary
X11 Excellent rating of personnel physical examination results (%)	[0.1, 0.0333, 0.000333]	[0.3, 0.0333, 0.000333]	[0.5, 0.0333, 0.000333]	[0.8, 0.0667, 0.000667]
X12 Psychological evaluation scores are good or higher in the past year (%)	[0.2, 0.0667, 0.000667]	[0.6, 0.0667, 0.000667]	[0.85, 0.00167, 0.000167]	[0.95, 0.0167, 0.000167]
X13 Excellent and good ratings of physical fitness training in the past year (%)	[0.1, 0.0333, 0.000333]	[0.3.0.0333, 0.000333]	[0.45, 0.0167, 0.000167]	[0.75, 0.0833, 0.000833]
X14 Passing rate of personnel emergency disposal assessment in the past year (%)	[0.3, 0.1, 0.001]	[0.7, 0.0333, 0.000333]	[0.85, 0.0167, 0.000167]	[0.95, 0.0167, 0.000167]



(a) The grey cloud model of excellent rating of personnel physical scores examination results

(b) The grey cloud model of psychological evaluation are good or higher in the past year

(c) The grey cloud model of excellent and good ratings of fitness training assessment in the past year

(d) The grey cloud model of passing rate of personnel physical personnel emergency disposal assessment in the past year

Fig. 2. The gray cloud model.

other. This cross shows that a particular value in the horizontal axis has different whitening weights for different gray classes, reflecting the model's fuzziness and grayness.

3.3. Results for risk hierarchical control policy

The ultimate purpose of risk assessment is to timely control the risk factors, reduce risk to an acceptable level through control measures, and realize closed-loop risk management. The hierarchical risk control mode is an effective strategy for improving the risk control level of social emergency rescue organizations. Different coping strategies are adopted according to the different risk levels. The comprehensive safety risk levels, state descriptions, and coping strategies of social emergency relief organizations are listed in Table 4.

The accident prevention of the 3 E (Engineering, Enforcement, and Education) strategy theory [36] was adopted. Based on the results of the risk assessment and combined with the actual management of social emergency rescue organizations, five aspects must be considered, namely, engineering technology, system mechanism, education and training, individual protection, and emergency treatment. In the process of formulating improvement measures, careful consideration should be given to whether the risk can be reduced to an acceptable level using scientific, reasonable, feasible, and reliable means; whether new risks will be generated in the

Table 4
Social emergency rescue organization comprehensive security risk state description and coping strategies.

Risk level	State description	Coping strategy
Level 1 (significant risk)	High risk of participating in rescue and relief missions	Take control measures for risk factors and continuously strengthen monitoring
Level 2 (considerable risk)	Greater risk of participating in rescue and relief missions	Take control measures for risk factors and continuously monitor them
Level 3 (general risk)	General risk of participating in rescue and relief missions	Take control measures for risk factors
Level 4 (low risk)	Low risk of participating in rescue and relief missions	The routine operation, regular monitoring

control process; and whether the control method can be practically applied.

1) Engineering technology. Risk control, prevention, and isolation are three aspects of the realization of technical measures to control inherent risks. For risky equipment or facilities, it is necessary to timely determine the cause and replace, augment, or enhance maintenance, testing, and repair to maintain the relevant equipment or facilities in good operational condition and reduce risks during task execution;
2) System mechanism. By rebuilding, supplementing, and improving the existing management system, a standardized, scientific, and systematic system management mechanism can be established to improve the working mode and strengthen the safety responsibility management and responsibility investigation process;
3) Education and training. Safety education should be strengthened by implementing multilevel, multichannel, and various methods of targeted education so that all personnel can gain safety awareness, master the technical skills of the position, be aware of significant safety risks in the execution of tasks, and know the consequences of illegal operations;
4) Individual protection. By augmenting or optimizing the individual equipment of operators and officers, the ability to control risks can be enhanced, and the damage caused by risks can be reduced. Psychological assistance training enhances the self-psychological counseling and emotional control ability of personnel to prevent accidents caused by psychological factors due to misoperation. At the same time, psychological assistance training can discover the hidden psychological disorders and diseases of personnel to allow early intervention or treatment and eliminate hidden risks;
5) Emergency treatment. The management of risk plans for significant tasks should be improved by raising the awareness of task risk management, strengthening the management of core tasks, conducting essential supervision of high-intensity tasks, reducing the impact of uncontrollable factors, and reducing the frequency of accidents and personnel economic losses.

4. Case study

In Province X, 10 cities and districts suffered extraordinary rainstorms, while 29 cities and districts experienced heavy rainstorms. The heavy rainfall caused flooding in the villages of these cities and districts. Province X was upgraded from a Level 4 emergency response to a Level 2 emergency response. Under the continuous influence of heavy rainfall, a river section burst its banks by more than 40 m, and eight downstream villages were flooded. Landslides, mudslides, and other dangerous situations occurred in some areas. Some roads were closed and power, water, and gas supply as well as communications were interrupted. Local authorities scrambled to manage the disaster. The government organized social emergency rescue forces for flood fighting and rescue work.

Two rescue teams were dispatched for application analysis of the flood fighting and rescue tasks. The practicability, accuracy, and operability of the model were verified by analyzing and calculating the risk levels of the two teams participating in the rescue and relief tasks.

Table 5
Actual values of evaluation indicators.

Index	Team A	Team B
X_{11} Excellent rating of personnel physical examination results (%)	0.73	0.78
X_{12} Psychological evaluation scores are good or higher in the past year (%)	0.9	0.81
X_{13} Excellent and good ratings of physical fitness training in the past year (%)	0.68	0.53
X_{14} Passing rate of personnel emergency disposal assessment in the past year (%)	0.78	0.88
X_{15} Passing rate of self-rescue and mutual rescue skills assessment in the past year (%)	0.92	0.87
X_{21} The rationality of general emergency equipment	95	87
X_{22} General emergency equipment completeness	97	91
X_{23} General emergency equipment condition	99	88
X_{24} Failure rate of universal emergency equipment (%)	0.01	0.04
X_{25} Special professional emergency equipment is reasonably equipped	92	93
X_{26} Failure rate of special specialized emergency equipment (%)	0.01	0.02
X_{27} Mechanized rescue equipment periodic maintenance rate (%)	0.96	0.96
X_{28} Mechanical rescue equipment failure rate (%)	0.01	0.04
X_{31} The rationality of personnel formation	89	92
X_{32} Special analysis of the safety situation before the mission	78	91
X_{33} Safety education of personnel before performing tasks	89	90
X_{34} Adequacy of food supplies	91	92
X_{35} Adequacy of fuel supplies	93	94
X_{36} The perfection of medical first aid guarantee	92	89
X_{37} The perfection of the alert system	91	88
X_{38} Coordinate with local government, social groups, international organizations and other parties	82	78
X_{41} The possibility of natural disasters (such as rock falls and debris flows) occurring around the rescue site	90	90
X_{42} Local social security situation	95	95
X_{51} Start-up number	121	98
X_{52} Number of vehicles deployed (units)	10	8
X_{53} Estimate the task duration (day)	7	7
X_{54} Task intensity	70	70
X_{55} Task situation judgment	92	88
X_{56} Clarity of task plan content	95	78

4.1. Data collection of rescue teams

Social emergency rescue Team A. This team had more than 160 members and since its establishment, more than 200 dispatches involving more than 3800 people had been made. The team dispatched 10 rescue vehicles with an average service life of 2.34 years. In addition, the team's rescue, protective, and communication equipment had the latest configuration and could be timely updated to perform missions quickly and safely. Before implementing the mission, comprehensive rescue action plans were formulated, coordinated, and communicated with the local government to fully understand the latest development in the flood disaster. Overall, rescue Team A had robust equipment and good understanding of the task situation.

Social emergency rescue Team B. This team comprised 98 retired soldiers as regular members. Since its establishment, the team had participated in rescue and relief 123 times. The team was equipped with eight rescue vehicles of various types with an average service life of 5.75 years. Some equipment and facilities had suffered wear and tear and were updated rapidly. After receiving the task notice, the organization carefully analyzed the safety situation and personnel for flood disaster safety education. Overall, the professional quality of Team B was good and the implementation of various management systems was relatively perfect.

According to the risk assessment indicators and grading standards in section 3.2, ten experts are invited to score the actual situation of the two teams. The actual values of the evaluation indicators are shown in Table 5.

4.2. Comparison and comprehensive analysis of evaluation results

The weights of each evaluation indicator are calculated according to the steps of the weighting method of Eqs. (1)–(3). Taking "personnel" in the first-level indicator as an example, the weights are showed in Table 6. The index weight of excellent rating of personnel physical examination results has a great impact on the risk of social emergency rescue organizations. Therefore, strengthening and improving the health level of personnel should be focused.

The risk level was calculated using the comprehensive safety risk assessment model. The average gray cloud whitening weight of each evaluation index was obtained using Eqs. (12) and (13). The comprehensive clustering coefficients of the two teams were then calculated using Eq. (14), and their comprehensive safety risk levels were finally obtained. The evaluation results are presented in Table 7. As indicated, the overall risk of Team A is low (Level 4) with the IV blue alert, whereas that of Team B is average (Level 3) with the III yellow alert. Although the overall risk of Team A is low, significant risks exist. Natural disasters (such as rock falls and debris flows) are highly likely to occur around the rescue site, so control measures should be taken. Compared with Team B, the overall status, quality and ability of Team A is lower. Team B's risk level is generally higher than Team A's, but there is no significant risk. Sufficient attention should be paid to the details, such as strengthening multi-party coordination with local governments and social groups and paying attention to personnel safety education.

4.3. Control measures and suggestions

Based on the evaluation results, control measures should be implemented for the different risk levels. The overall risk level of Team A is 4, indicating that the risk of the team participating in rescue and relief tasks is low and it can execute the task immediately. However, attention should be paid to the risks during the execution process and the dynamic changes in risk factors. In particular, in the execution of a task in a harsh environment, secondary disasters can occur. The overall risk level of Team B is 3, indicating that the risk of the team participating in rescue and relief tasks is average, and control measures should be taken according to the risk factors. Regarding flood fighting and rescue tasks, the two teams should pay attention to the critical links of risk before execution of the tasks: 1) personnel should be organized reasonably and responsibilities should be clarified layer by layer; 2) explain the key links and points of attention of flood rescue to the task personnel, strengthen the professional training of boat operation and rescue, organize the equipment and facilities used to familiarize themselves with the performance and practical operation, optimize the operation standards and points of equipment and facilities, and enhance the emergency disposal ability; 3) actively communicate with the local meteorology, hydrology, water conservancy, and other departments to ensure the safety of rescue personnel and strengthen rescue linkages; 4) understand the flood dynamics and water level changes around the mission area, improve the safety warning system, put safety warning signage for complex and dangerous areas, and provide early warnings of dangerous situations to prevent accidents.

Because of the risk factors of Team B, the recommended management and control measures are as follows: 1) optimize the rationality of rescue equipment and facilities, and check whether the equipment and facilities are equipped with complete components, have full coverage of functions, adequate advancement of functions, and can meet the actual needs of rapid mobilization, transportation, and arrival; 2) replace, augment, or repair equipment and facilities with high failure rates; 3) ensure the safety of personnel,

Table 6
Weight calculation results of "Personnel" indicator.

Index	Weight
X_{11} Excellent rating of personnel physical examination results (%)	0.088321
X_{12} Psychological evaluation scores are good or higher in the past year (%)	0.041123
X_{13} Excellent and good ratings of physical fitness training in the past year (%)	0.037238
X_{14} Passing rate of personnel emergency disposal assessment in the past year (%)	0.037124
X_{15} Passing rate of self-rescue and mutual rescue skills assessment in the past year (%)	0.038695

Table 7
Social emergency rescue organization rescue mission comprehensive safety risk results.

Name of rescue team	Comprehensive clustering coefficient				Risk level	Warning level
	Level one	Level two	Level three	Level four		
Team A	0.059	0.096	0.236	0.750	Fourth level risk	Blue alert
Team B	0	0.235	0.637	0.268	Tertiary risk	Yellow alert

improve the efficiency of disaster relief, and appropriately equip them with new high-tech devices, in addition to enhancing conventional equipment and facilities; 4) plan and improve the support systems by reviewing all support plans and strengthening the support capacity of materials, transportation, catering, power, communication, etc.

5. Conclusion

This study analyzed and researched the HSE comprehensive safety risk of social emergency rescue organizations in rescue and disaster relief. Social emergency rescue organizations' risk factors were identified from five aspects: personnel, equipment and facilities, management, environment and tasks. A risk assessment index system has been established, including 16 secondary indexes and 29 three-level indexes. Based on historical data and expert scores, a four-level grading standard for evaluation indicators was established to realize the quantitative transformation of indicators. An evaluation method according to the gray cloud model was proposed to effectively deal with the fuzzification of risk level boundary and the randomness of evaluation index data. A four-level risk warning and control mechanism has been established. The risk management and control strategy possess five aspects: engineering technology, system mechanism, education and training, individual protection and emergency treatment. Closed-loop risk management was realized. The model was applied to a flood rescue task. The maximum clustering coefficient determined the risk levels of the two organizations. Team A's risk level was lower than Team B's. Hence, corresponding control measures were proposed. The risk assessment system, risk early warning and control strategy proposed have strong applicability and practicability, which can guide the risk control practice of social emergency rescue organizations.

Data availability statement

Data will be made available on request.

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CRediT authorship contribution statement

Mengyao Wang: Writing – review & editing, Writing – original draft, Visualization, Data curation, Conceptualization. **Haoying Zhang:** Writing – original draft, Investigation, Formal analysis. **Yun Luo:** Writing – review & editing, Validation, Supervision, Project administration. **Ming Xu:** Writing – review & editing, Validation, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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