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Study on the Effectiveness of the Integral Emergency Response System for Coal Mine Water Hazard Accidents Based on Combination Weighting

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Abstract: Improving the emergency response effectiveness of coal mines in response to water hazard accidents not only plays a vital part in minimizing the resultant losses, but also functions as an important index for evaluating the emergency response capability of coal mines. Therefore, it is of great necessity to test the emergency response capability of coal mines. In this study, an effectiveness measurement index system for the emergency response system that comprises two primary indexes (i.e., response capability and service capability) and six secondary indexes (i.e., accident information transmission, emergency command and control, emergency rescue and mitigation, emergency management, personnel team, and prevention and preparation) was constructed. Additionally, a technique for order preference by similarity to ideal solution (TOPSIS) model for evaluating the effectiveness of the integral emergency response system for coal mine water hazard accidents, based on combination weighting, was put forward. Both the empirical evaluation and model validation of the emergency response system for water hazard accidents were carried out by taking five coal mines attached to Henan Coking Coal Group as research objects. The findings suggest that the effectiveness of the emergency response system for water hazard accidents in the Guhanshan Coal Mine and the Zhongmachun Coal Mine is rated as "average", while those in the Jiulishan Coal Mine, Zhaogu No. 1 Coal Mine, and Zhaogu No. 2 Coal Mine are graded as "good". This result is consistent with the actual situation, which verifies the capacity of the proposed TOPSIS model to evaluate the emergency response system scientifically and efficiently for coal mine water hazard accidents. This study not only offers new ideas for how to enhance the comprehensive emergency response capability of coal mines with respect to water hazard accidents, but also provides support for making decisions concerning the upgrading of the emergency response capacity of coal mines.

Keywords: coal mine safety; water hazard accidents; emergency response; effectiveness measurement

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1. Introduction

The abundant coal resources carry great weight in China's national economy. After more than a century of mining, most of the mines in China intend to switch their attention to the mining of lower coal groups [1]. As the mining time and depth increase, the hydrogeological conditions of mines in China have become increasingly complex. As such, China has become one of the countries suffering from the most serious coal mine water hazard accidents in the world [2,3]. The statistical materials analysis shows that a total of three major water hazard accidents and six less serious water hazard accidents took place in coal mines across the country from 2020 to 2022, claiming the lives of 78 people.

Additionally, multiple water-related accidents also occurred in the meantime [4]. Accident emergency response plays a vital role throughout accident emergency management. It can not only reflect whether prevention and preparation before the accident are in place but can also speed up emergency response and rescue. Raising the emergency response speed of coal mine water hazard accidents proves to be the key to reducing its severity. For this purpose, coal mining enterprises are urged to make greater efforts to enhance their emergency response capabilities. On this account, measuring and evaluating the effectiveness of accident emergency response systems in coal mining enterprises serves as a touchstone for testing the quality of emergency management in related coal mining enterprises. This work is of prime importance for implementing coal mine safety production requirements and supervising coal mine safety production emergency management.

Water hazard accidents are one of the five most commonly seen disasters in coal mines. In this regard, scholars all over the world have chiefly focused on the influence of waterproof mechanisms and structural cracks on water hazard accidents, as well as water hazard accident mechanisms during pressurized mining. Snow and Louise et al. [5,6], to name a few, applied the method for calculating permeability tensor to coal mine water hazard accidents and constructed an anisotropic fractured medium seepage model. Santos and Bieniawski et al., centering on the mechanism of bottom plate failure, introduced the concept of "critical capacity release point" and widened the application range of the water disaster causation theory by refining the Hoek–Brown rock strength criterion [7–10]. As for Chinese scholars, they have focused their research on analyzing why water hazard accidents happen and how they evolve. For instance, Wang, after giving a detailed analysis on the causes of water hazard accidents, classified the causal factors into five categories and constructed a coal mine accident causation model based on management errors [11]. Zhang et al. set up a three-dimensional water disaster prevention and control technology system and refined it into two subsystems: surface water and groundwater [12]. Zhao conducted fuzzy clustering analysis on the causes of water hazard accidents with the aid of MATLAB. Following the analysis, four types of water disasters in coal mines were identified, which greatly accelerates the judgement on the causes of water hazard accidents [13]. Miao et al. [14] looked at the basic situation and the problems of coal mine water hazard accidents in China in 2020 and attributed the disasters to six aspects of factors. Sun et al. [15] compiled data from 2000 to 2015 and found that the number of deaths in a single major water accident ranked first. Wei et al. [16] conducted a hierarchical and classified statistical analysis on the relevant information on coal mine water hazard accidents that occurred in China from 2001 to 2013, further clarifying the relationship between relevant factors and coal mine water hazard accidents. Yin et al. [17] investigated the main reasons for water hazard accidents and proposed corresponding technical measures to standardize the process of detecting and releasing water with pilot holes. Zhang et al. [18] collected and researched the information on water hazard disasters in China between 2008 and 2020. In addition, Bascetin et al. reduced the cost of tailings pond leakage prevention from the perspective of improvement of seepage control materials, which provided a new management idea for the prevention of water damage accidents in coal mines [19]. Based on the results, the provinces where water hazard accidents frequently occurred were realized.

Coal mining is not only severely restricted by water resources, but also has more and more obvious influence on groundwater resources. Jia Xin, He Ruimin et al. revealed the influence and rule of surface cracks formed by coal mining on the vertical gradient of surface water content by monitoring the evolution process of ecological environment and the dynamic distribution of surface cracks in different periods of collapse [20]. Lu Zhen, Guo Yangnan et al. adopted the CCME-WQI method to carry out the water quality assessment of different water bodies in mining areas, and established water quality health risk assessment models to analyze water quality health risks of different populations in mining areas and their spatial distribution characteristics, so as to grasp the water quality characteristics and health risks of various water bodies in mining areas, which is of great significance for rational development and utilization of water resources in mining areas [21]. Li Qiming, Zhai Lijuan et al. proposed that the damage types of karst aquifer caused by coal mining could be divided into three types: direct damage, indirect damage, and non-impact damage; the damage modes of aquifer caused by coal mining could be divided into three types: "roof pore water destruction", "floor karst water destruction", and "karst water, fissure water, pore water destruction" [22]. Cao Zhiguo, He Ruimin et al. summarized three types of groundwater migration laws in four stages of stability in pre-mining, mid-mining, post-mining, post-mining under large-scale, and high-intensity modern coal mining conditions [23]. Ning Jianhong, Jia Xirong et al. discussed the method of determining the work grade of groundwater environmental impact assessment in the coal mine area combined with the type of deposit exploration [24]. Fan Limin, Kou Guide et al. have studied the variation law of shallow groundwater flow field under coal mining conditions [25], and these results have provided references for the scientific protection and rational utilization of water resources in mining areas.

China is one of the most serious countries suffering from mine water [26]. The underground water rushes into the underground mining space by means of the roof and floor water channel, causing great casualties and property losses. Therefore, one of the key scientific issues to realize the scientific mining of coal mines is the prevention and control of water disasters and the protection and utilization of water resources [27,28]. In recent years, China has made great achievements, solved many problems, and achieved great benefits in the prevention and control of water hazards in coal mines. Many scholars at home and abroad have also made rich achievements in the theoretical research of water damage control in coal mining. These studies mainly focus on the hydrogeological characteristics of coal mining, the risk assessment of water disaster in coal mining, and the comprehensive water disaster prevention technology in coal mining, etc. For example, in terms of hydrogeological characteristics of coal mining, ZhaopingMeng and GuoqingLi [29] studied the permeability behavior and influencing factors of high grade coal in the early depletion process of coalbed methane. DongshengZhang et al. [30,31] pointed out that the large-scale mining of shallow coal seams has an important impact on the overlying aquifer and the surface ecological environment. In order to protect the aquifer and maximize the exploitation of coal resources, field tests were carried out during the mining of LW32201 in Bulianta Coal Mine, Shendong. ZhenHuang et al. [32,33] found that the hydraulic characteristics of the strata under the floor of coal seams were an important factor in evaluating the water inrush risk of the floor, but the laboratory hydraulic test could not accurately determine the water inrush risk of the floor. In the study of coal mining flood risk assessment, water inrush coefficient is often used to predict flood risk in the world, such as the Kriging interpolation method [34,35]. In terms of comprehensive water disaster prevention and control technology in coal mines, the active protection method is mainly adopted in foreign countries to prevent and control water inrush, using vertical ground drilling and submersible pumps with high lift (1000 m), large displacement (5000 m^3/h), and high power (2000 KW) to drain aquifers [29]. Domestic coal mine water prevention and control technology mainly has two aspects: one is blocking, the other is sparse; these can be present in combination with one another. For example, Hu Weiyue [36], starting with the spatio-temporal changes of coal seam mining and the evolution process of underground water flow, proposed that the water filled in the roof aquifer during shallow coal seam mining is composed of fluctuating static storage water release and incremental dynamic recharge water, and proposed a spatio-temporal dynamic prediction method of mine water inrush with the mining process. TieLi et al. [37] took a water-bearing alluvial layer as an example and evaluated the stress redistribution, formation failure, and enhanced water conductivity caused by coal mining in Daliuta Coal Mine in Shaanxi Province through field investigation, physical simulation, and numerical analysis.

Through a review of the literature, it is found that current research on coal mine water hazard accidents primarily focuses on the prediction, exploration, management, monitoring, and early warning of water hazard accidents. By contrast, there is scarce research on the emergency response capability of coal mining enterprises to water hazard accidents. As one of the five major disasters in coal mines, water hazard accidents have risen to be the second largest "killer", second only to gas accidents in terms of threatening coal mine safety production and personnel life safety.

Coal mine accidents are characterized by suddenness, uncertainty, disastrous, and secondary nature. Effective emergency response serves as a vital approach to mitigate losses brought by major disasters and accidents and prevent further damage [38]. In this paper, an evaluation system targeting the effectiveness of the integrated emergency response system for coal mine water hazard accidents was constructed to test and assess the emergency system response efficiency of coal mining enterprises. This move aims to promote coal mining enterprises to upgrade their emergency response capabilities for accidents and disasters, thus maximizing the efficiency of coal production and disaster prevention and control. Moreover, this paper provides ideas for safe and efficient mining, water disaster prevention, and control in coal mines.

2. Construction of the Effectiveness Measurement Index System

2.1. Connotation of the Integrated Emergency Response System for Coal Mine Water Hazard Accidents

The emergency response system for coal mine water hazard accidents is a collection of various organizational personnel, equipment, emergency treatment steps, plans, and their interrelationships involved in the response and disposal by coal mining enterprises in the face of water hazard accidents. By this token, it is also the interaction between accident classification and response levels. The integrated emergency response system for coal mine water hazard accidents is a highly targeted, interconnected, and complex giant system that links the stages of emergency life cycle management, covering preparation, prevention, response, and recovery. In the production and operation activities of coal mining enterprises, numerous cases of accidents being exacerbated by delayed emergency response crop up here and there, indicating an urgent need for coal mining enterprises to optimize their current accident emergency response systems, as well as their normalized emergency services and abnormal emergency response capabilities.

Guo, Zhang, and Zhang et al. divided the integrated emergency response system into response capability and service capability in the estimation of added value for integrated emergency response systems [39]. Given the fact that the emergency response process and steps for different accidents are similar, this paper transforms the evaluation of the emergency response capability for coal mine water hazard accidents into a measurement of the effectiveness of the integrated emergency response system for coal mine water hazard accidents. The measurement covers two dimensions: abnormal response capability and normalized service capability. Evaluations of these two capabilities can not only reflect the efficacy of emergency management prevention and preparation in coal mining enterprises, but also detect the effectiveness of emergency management monitoring and early warning in coal mining enterprises. Furthermore, it also plays a role in affecting the scale, speed, results, and effectiveness of emergency response and rescue, as well as recovery and reconstruction in coal mining enterprises. Therefore, this paper takes advantage of response capability and service capability in order to measure the effectiveness of the integrated emergency response system of coal mining enterprises.

2.2. Construction of the Effectiveness Measurement Index System for the Integrated Emergency Response System for Coal Mine Water Hazard Accidents

With respect to effectiveness measurement of the integrated emergency response system for coal mine water hazard accidents, the number of indexes is not the only factor that matters; the applicability and appropriateness of measurement indexes also make a difference to the accuracy of the results. Therefore, in accordance with the principles of independence, scientificity, and data availability, as well as existing research results and suggestions from experts in the field of coal mine safety emergency response, this paper provides an in-depth analysis of the construction of the validity measurement index system based on the AHP methodology (Table 1) [40].

Table 1. Efficiency measurement index system of comprehensive emergency response system for coal mine water disaster accidents.

Target Layer	Criterion Layer	Sub-Criterion Layer	Index Level	AHP Weight	Entropy Method Weight	Combined Weight
Efficiency measurement index system of comprehensive emergency response system for coal mine flooding accident	B_1 Responsiveness	C_1 Accident information transmission	Hazard identification capability C_{11}	0.0419	0.0378	0.03985
			Prediction ability of water exploration and release C_{12}	0.0496	0.0541	0.05185
			Water damage cause analysis capacity C_{13}	0.0463	0.0490	0.04765
			Accident information alarm capability C_{14}	0.0371	0.0356	0.03635
			Accident information reporting ability C_{15}	0.0325	0.0309	0.0317
		C_2 Emergency command and control	Accident identification and control handling capability C_{21}	0.0341	0.0309	0.0325
			The emergency broadcast system is scientific C_{22}	0.0301	0.0356	0.03285
			Emergency command authority activation capability C_{23}	0.0445	0.0378	0.04115
			Disaster relief command and coordination ability C_{24}	0.0381	0.0425	0.0403
		C_3 Emergency rescue and mitigation	Quality of rescue team C_{31}	0.0474	0.0464	0.0469
			Medical security level C_{32}	0.0299	0.0464	0.03815
			Technical support C_{33}	0.0315	0.0309	0.0312
			Security monitoring system running status C_{34}	0.0464	0.0309	0.03865
			Video surveillance system running status C_{35}	0.0303	0.0309	0.0306

Table 1. *Cont.*

Target Layer	Criterion Layer	Sub-Criterion Layer	Index Level	AHP Weight	Entropy Method Weight	Combined Weight
Efficiency measurement index system of comprehensive emergency response system for coal mine flooding accident	B_2 Service capability	C_4 Emergency management dimension	Safety input level of coal mine C_{41}	0.0253	0.0253	0.0253
			Completeness of emergency response system C_{42}	0.0253	0.0283	0.0268
			Perfection of emergency materials reserve management system C_{43}	0.0253	0.0253	0.0253
			Framework of the responsibility system for preventing and controlling water C_{44}	0.0283	0.0253	0.0268
			Contingency plan preparation, training, and exercise rationality C_{45}	0.0283	0.0283	0.0283
		C_5 Personnel team dimension	Knowledge level of water damage accidents C_{51}	0.0303	0.0283	0.0293
			Safety accident attitude concept C_{52}	0.0407	0.0427	0.0417
			Code of conduct for work safety C_{53}	0.0283	0.0283	0.0283
		C_6 Prevention of preparation dimension	Rationality of mine drainage system C_{61}	0.0493	0.0483	0.0488
			Water safety training and warning education level C_{62}	0.0387	0.0366	0.03765
			Emergency rescue equipment and materials level C_{63}	0.0472	0.0503	0.04875
			Spatial accessibility of emergency supplies C_{64}	0.0425	0.0412	0.04185
			Emergency response exercise and summary normative C_{65}	0.0508	0.0521	0.05145

2.3. Determination of Combination Weights of the Effectiveness Measurement Indexes for Emergency Response System

2.3.1. AHP Method for Determining Subjective Weights of Measurement Indexes

The subjective weights discussed in this paper are determined according to the following procedure.

Step 1: divide the selected and integrated measurement indexes into levels and construct a tree-shaped decision-making framework consisting of the "target-criterion" layer, the "criterion-sub criterion" layer, and the "sub-criterion -index" layer (as exhibited in Table 1).

Step 2: Invite 25 experts in the field of coal mine water hazard accidents to compare the relative importance of the established indexes pairwise, according to the 1–9 scale method created by Schaty. According to the results, a judgment matrix F_{i} between adjacent levels is hereby constructed. This step is designed to make the subjective weights of indexes more convincing and credible.

Step 3: Based on the comparison results, figure out the relative importance of each index under established conditions and determine the judgment matrix of the "index-target" layer, and then work out the objective weights of each level. It is noteworthy that the concept of "established conditions" here refers to the relative importance of each index in the corresponding (sub) criterion layer (single hierarchical ranking) and in the target layer (total hierarchical ranking). Among them, relative importance can be converted to weight in light of the rule that the stronger the relative importance, the greater the corresponding weight.

Step 4: Consistency test. This means testing the logical rationality of the determined index weights. Following programming and calculation in MATLAB 2021, as well as continuous adjustment and correction of the judgment matrix, all matrices were subjected to the consistency test. The subjective weights of each index were also determined (as presented in Table 1).

2.3.2. Entropy Method for Determining Objective Weights of Measurement Indexes

The entropy method functions as an objective evaluation method, and its underlying rule is the greater the amount of information, the smaller the uncertainty, and the lower the entropy value, and vice versa [41,42]. The objective weights are determined on the strength of the standardized initial matrix E. This study adopts the "backward induction" method to calculate objective weights (Table 1). The specific calculation process is introduced here:

$$W_{E_j} = \frac{1 - e_j}{\sum\limits_{j=1}^{n} (1 - e_j)} \tag{1}$$

where e_j is the entropy value of the influencing factor. Since the value of weight W depends on the proportion of the entropy value of the index, working out the entropy value of the index is a must, which can be counted by the equation below:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} Q_{ij} \times \ln Q_{ij} \tag{2}$$

where Q_{ij} is the proportion of the index, and it can be expressed as:

$$Q_{ij} = \frac{E_{ij}}{\sum\limits_{i=1}^{m} E_{ij}}, Q_{ij} \in [0, 1] \tag{3}$$

where E_{ij} is the term of the standard matrix.

2.3.3. AHP and Entropy Methods for Determining Combination Weights by Establishing a Combination Weighting Model

The AHP method determines weights by means of comparing the preferences and importance of every two indexes, usually adopting a 1–9 scale. Differently, the determination of objective weights through the entropy method relies on calculating the entropy value of the collected data. The key to AHP is quantifying human subjective judgments, so that the index weights determined by AHP are more subjective, while the entropy method puts greater emphasis on the quantitative calculation of the data. Consequently, the index weights determined by the entropy method fail to reflect which index the evaluator prefers. Even worse, the results may contradict the actual situation.

In summary, this paper adopts both AHP and entropy methods for combination weighting, effectively minimizing subjective influence and objective data defects, and enhancing the scientificity and rationality of the index weight values. In addition, the Lagrangian function, based on the AHP and entropy methods for weights, was also introduced to facilitate the construction of the decision model, and the Euclidean distance function was employed to construct the relationship equation between subjective and objective weights and preference coefficients. With these measures, the optimal combination weight comes into being [42].

The decision model can be represented as:

$$\begin{cases} W_j = \beta W_{Aj} + \lambda W_{Bj} \\ \beta + \lambda = 1 \end{cases} \quad (4)$$

where W_{Aj} is the subjective weight; W_{Bj} is the objective weight; β and λ are preference coefficients for the subjective and objective weights.

The Euclidean distance can be calculated as follows:

$$\begin{cases} M(W_{Aj} - W_{Bj}) = \sqrt{\sum_{j=1}^{n} (W_{Aj} - W_{Bj})^2} \\ M(W_{Aj} - W_{Bj})^2 = (\beta - \lambda)^2 \end{cases} \quad (5)$$

2.4. Grading of Emergency Response System Effectiveness for Coal Mine Water Hazard Accidents

Based on the connotation of the effectiveness of the emergency response system in coal mining enterprises, this paper considers the measurement variable value range of the effectiveness of the emergency response system in coal mining enterprises as [0, 1]. In light of the standard of the five-level evaluation method, as well as suggestions from experts in the field of emergency response to coal mine water hazard accidents, the emergency response capacity of coal mining enterprises for water hazard accidents falls into five levels (Table 2).

Table 2. Standard set of efficiency classification of emergency response system in coal mine enterprises.

Evaluation Level	Rank Scale	Equal Efficiency Score Interval
optimal	I	(0.9, 1.0]
good	II	(0.8, 0.9]
normal	III	(0.7, 0.8]
range	IV	(0.6, 0.7]
Very bad	V	[0, 0.6]

3. Construction of a Fuzzy Evaluation Model for the Effectiveness of Integrated Emergency Response System for Coal Mine Water Hazard Accidents

3.1. Establishment of a Dimensionless Original Data Matrix

As previously discussed, the measurement model constructed in this paper utilizes multiple indexes for comprehensive evaluation. For this reason, to eliminate the influence of diversity from evaluation indexes with different dimensions and orders of magnitude, the first step is to standardize the original data. Only in this way can the reliability of the results be enhanced. The specific standardization steps are as follows:

Step 1: Store the original data in the form of a spatial matrix and accordingly establish a spatial matrix *D*. Among them, each row represents a coal mine, and each column stands for an index. That is, matrix *D* is composed of *m* coal mines and *n* indexes;

Step 2: Standardize the data (dimensionless processing);

Step 3: Output a new matrix *E*, which serves as the source data for subsequent measurement.

The expression of the matrix is:

$$D = [D_{ij}]_{m \times n}; i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \tag{6}$$

The calculation formula for standardized processing in Step 2 is as follows:
The formula for standardizing positive indexes:

$$E_{ij} = \frac{C_{ij} - \min(C_j)}{\max(C_j) - \min(C_j)} \tag{7}$$

The formula for standardizing negative indexes:

$$E_{ij} = \frac{\max(C_j) - C_{ij}}{\max(C_j) - \min(C_j)} \tag{8}$$

The output new matrix E can be represented as:

$$E = [E_{ij}]_{m \times n}; i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n \tag{9}$$

3.2. Calculation of the TOPSIS Model

The technique for order preference by similarity to ideal solution (TOPSIS) method [43], which is commonly used in the multi-objective analysis of practical solutions in systems engineering, has been extensively applied in numerous fields. The basic idea behind this method is that the positive and negative ideals of the final solution form a space based on a normalized initial data matrix, and the evaluated solution is regarded as a point in this space. By calculating the distance between this point and the positive and negative ideal solution, the relative closeness, $d_{i,}$ between the evaluated scheme and the positive or negative ideal scheme can be deduced, and the effectiveness of the scheme can therefore be realized.

Single index evaluation: supposing that the weight distributed to indexes in C_x is Q, and that L is the single index evaluation matrix of C_x, then

$$K_i = Q \cdot L = (k_1, k_2, \ldots, k_y) \tag{10}$$

where K_i is the evaluation result of a single index in C_x.

Multi-index sequential evaluation: since indexes to be evaluated in this study are great in number, this paper adopts a calculation scheme of deriving evaluation results step by step by dividing them into different levels. The dominating evaluation principle is to determine the evaluation matrix of the index layer, the single, and the total ranking of the levels, and to conduct a comprehensive evaluation of each level using the "onion peeling" method.

Finally, the evaluation results are standardized to obtain the final scores of each evaluation object.

$$K'_i = \frac{K_i - \min(K_i)}{\max(K_i) - \min(K_i)} \tag{11}$$

4. Empirical Analysis on Coal Mines

On the grounds of factors like type of work, type of enterprise, and safety production standardization level, research samples are selected from four primary coal mines: Jiulishan Coal Mine, Guhanshan Coal Mine, Zhaogu No.1 Coal Mine, and Zhaogu No. 2 Coal Mine, and one secondary coal mine, i.e., Zhongmachun Coal Mine. These five coal mines, which are located in Jiaozuo City, Henan Province, Chiam, are chosen as the research objects for this study. Targeting safety management personnel, mine water prevention and control professionals, general practitioners, and other workers, extensive research was conducted. In addition, the effectiveness measurement index system and model of the emergency response system for water hazard accidents in coal mining enterprises constructed in this paper are adopted to empirically evaluate the five coal mines. Based on the results, the rationality of the theoretical model is further verified. This practice enjoys strong practical implications.

4.1. Data Source and Processing

The survey method adopted in this paper is questionnaire retention and collection, and the samples are collected from the five coal mines mentioned above. From September to October 2023, a total of 190 questionnaires were distributed on safety training sites, and 185 were collected back, among which 183 questionnaires were valid. Therefore, the response rate is 97.37%, and the effective response rate is 96.32% (Table 3).

Table 3. Statistical table of questionnaire data.

Number of Copies Issued	Recycled Copies	Recovery	Effective Copies	Effective Recovery
190	185	97.37%	183	96.32%

4.2. Questionnaire Reliability and Validity Test

An analysis on the reliability of the overall questionnaire reveals that $\alpha = 0.987$, greater than 0.9. The reliability analysis is also performed to target accident information transmission, emergency command and control, emergency rescue and mitigation, emergency management, personnel team, and prevention and preparation. The calculated α reads 0.906, 0.954, 0.944, 0.971, 0.917, and 0.978, respectively (Table 4), all exceeding 0.9, indicating that the questionnaire is highly consistent and valid.

Table 4. Questionnaire reliability analysis table.

Variable (Layer/Level)	Klonbach Coefficient	Item
Accident information transfer	0.906	5
Emergency command and control	0.954	4
Emergency rescue and mitigation	0.944	5
Emergency management dimension	0.971	5
Personnel team dimension	0.917	3
Preventive preparedness dimension	0.978	5
Overall questionnaire	0.987	27

The scale section of the questionnaire is subjected to KMO and Bartlett's tests. The results presented in Table 5 suggest that KMO values of both the total scale and various sub-scales are all greater than 0.7, with no significant difference (less than 0.05). That is, the questionnaire scale section turns out be applicable for exploratory factor analysis.

Table 5. KMO and Bartlett test tables.

Variable (Layer/Level)	KMO	Bartlett Sphericity Test		
	Exponent	Approximate Chi-Square	Degree of Freedom	Significance
Accident information transfer	0.755	242.547	10	0.000
Emergency command and control	0.818	298.787	6	0.000
Emergency rescue and mitigation	0.826	203.129	5	0.000
Emergency management dimension	0.754	201.075	10	0.000
Personnel team dimension	0.712	150.939	3	0.000
Preventive preparedness dimension	0.844	584.668	10	0.000

4.3. Result Analysis

4.3.1. Scores-Based Comprehensive Evaluation

The TOPSIS method is employed to comprehensively evaluate the five coal mines, and the comprehensive evaluation and ranking results are given in Table 6.

Table 6. Efficiency measurement of emergency response system for water disaster.

Symbol	Comprehensive Integral	Positive Ideal Solution Distance	Negative Ideal Solution Distance	Relative Proximity	Sort Result
A	78.78	7.544	0.000	0.000	5
B	81.31	3.960	3.584	0.475	2
C	80.02	0.000	7.544	1.000	3
D	84.12	5.790	1.754	0.232	1
E	79.64	6.329	1.216	0.161	4

Where A, B, C, D, and E, respectively, represent Guhanshan Mine, Jiulishan Mine, Zhaogu No. 2 Mine, Zhaogu No. 1 Mine, and Zhongmacun Mine.

It is evident in Table 6 that the comprehensive scores of the emergency response systems for water hazard accidents in the five coal mines are all above 75. Among them, the comprehensive score of the D Coal Mine ranks highest (84.12), while the A Coal Mine comes in last (78.78). By calculation, the average comprehensive score of the five coal mines is 80.77, and the standard deviation is 1.86. These values somewhat reflect that the emergency response ability for coal mine water hazard accidents in Jiaozuo is rated as “good”. Apart from the above efforts, the effectiveness of the emergency response system for coal mine water hazard accidents is also investigated from the perspective of the ownership of mines. After calculation, the following results are obtained:

(1) the average comprehensive score of the A Coal Mine, B Coal Mine, and E Coal Mine, which belong to the Coking Coal Group, is 79.91, with a standard deviation of 1.05;
(2) that of the C Coal Mine and D Coal Mine, which are members of Henan Coal Chemical Group, is 82.07, with a standard deviation of 2.05.

These figures disclose that the effectiveness of the emergency response system for water hazard accidents in the coal mines under the Coking Coal Group is slightly lower than that of the coal mines under the Henan Coal Chemical Group. Nevertheless, in terms of the differences in the effectiveness of the emergency response system for water hazard accidents among coal mines owned by them, the Coking Coal Group witnesses less difference. In summary, coal mines under the Coking Coal Group boast more sufficient ability for coordinated development than those attached to the Henan Coal Chemical Group.

The two indexes on the criterion level of the five coal mines include response capability B_1 and service capability B_2, and their measurement scores and comparison can be found in Figure 1.

Figure 1 gives a clear message that the response and service capabilities of the emergency response systems for water hazard accidents in the five coal mines all exceed 75. Among them, the response and service capabilities of the emergency response system for water hazard accidents in the D Coal Mine are evaluated as “good”. It is also the only mine among the five coal mines whose B_1 and B_2 scores reach 80 or above. Hence, other coal mines are highly recommended in order to learn from their construction experience, identify, and fill in gaps, in the hope of improving the effectiveness of the emergency response system. In addition, it is also revealed that the service capacity B_2 score of the C Coal Mine is relatively weak, which means obvious weak links exist in one or more dimensions, such as emergency management, staff allocation, and prevention preparation. For the A Coal Mine, its response capability B_1 score is relatively poor, which is reflected in one or more aspects of accident information transmission, emergency command and control, and emergency rescue and mitigation.

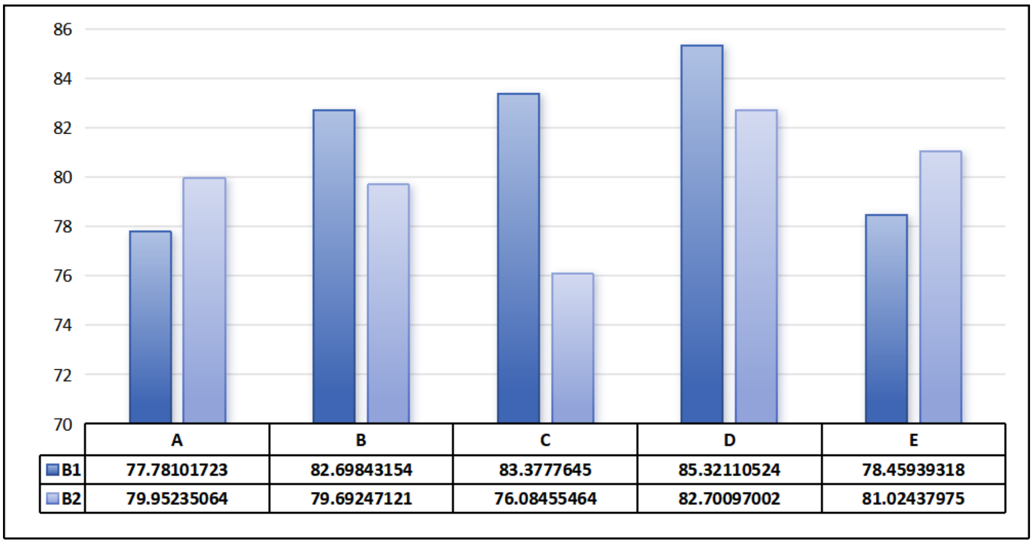

Figure 1. Statistical chart of index measurement scores at the criterion level.

The six indexes at the sub-criterion level of the five coal mines are made up of accident information transmission, emergency command and control, emergency rescue and mitigation, emergency management, personnel team, as well as prevention and preparation. The measurement scores and comparison are presented in Figure 2.

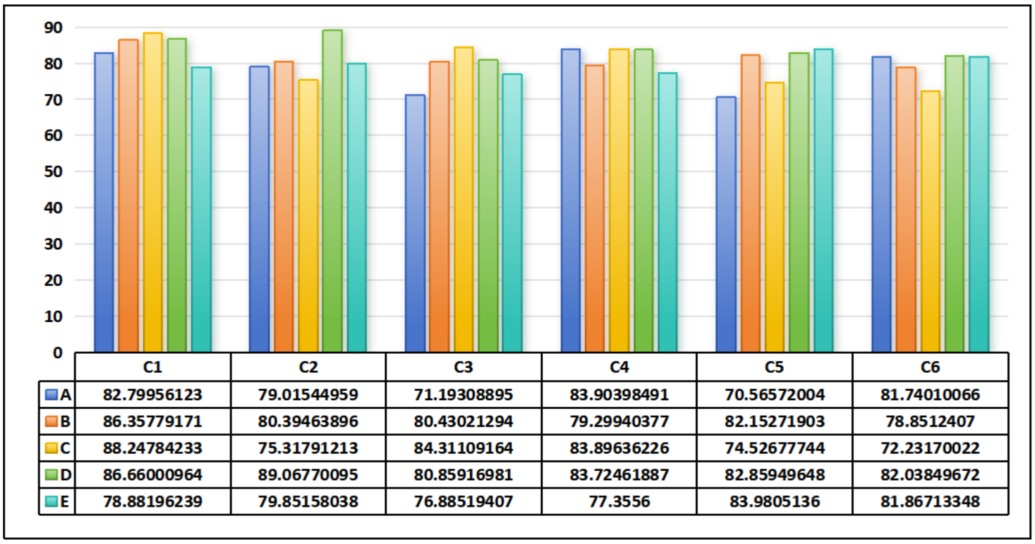

Figure 2. Statistical chart of index measure score of sub-criteria layer.

Based on the data shown in Figure 2, it is apparent that the six indexes at the sub-criterion level of the emergency response systems for water hazard accidents in the five coal mines are all rated above 75. Among them, the average scores of C_1~C_6 are 84.59, 80.73, 78.74, 81.64, 78.82, and 79.35, respectively, all of which are greater than 75. However, it is noteworthy that the average scores of C_3, C_5, and C_6 are less than 80, indicating that the development of the emergency response system for coal mine water hazard accidents lags behind on emergency rescue and mitigation, personnel team, as well as prevention and preparation. It is urgent for each coal mine to identify deficiencies and accelerate construction.

The effectiveness scores and ranking results after the standardization of the criterion and sub-criterion layers are counted and displayed in Table 7.

Table 7. Evaluation results of criterion level and sub-criterion level of water disaster emergency response system effectiveness measurement.

Symbol	Responsiveness B_1	Ranking	Symbol	Service Capability B_2	Ranking
A	0	5	A	0.58457	3
B	0.65216	3	B	0.54529	4
C	0.74226	2	C	0	5
D	1	1	D	1	1
E	0.08996	4	E	0.74660	2
Symbol	**Accident Information Transmission C_1**	**Ranking**	**Symbol**	**Emergency Command and Control C_2**	**Ranking**
A	0.41828	4	A	0.26892	4
B	0.79819	3	B	0.36922	2
C	1	1	C	0	5
D	0.83046	2	D	1	1
E	0	5	E	0.32973	3
Symbol	**Emergency Rescue and Mitigation C_3**	**Ranking**	**Symbol**	**Emergency Management C_4**	**Ranking**
A	0	5	A	1	1
B	0.70415	3	B	0.29683	4
C	1	1	C	0.99883	2
D	0.73658	2	D	0.97260	3
E	0.43391	4	E	0	5
Symbol	**Personnel Team C_5**	**Ranking**	**Symbol**	**Prevention of Preparation C_6**	**Ranking**
A	0	5	A	0.96957	3
B	0.86374	3	B	0.67499	4
C	0.29527	4	C	0	5
D	0.91643	2	D	1	1
E	1	1	E	0.98252	2

Frequency statistics are performed on the data in Table 7, and the results reveal that the highest score of a single criterion or dimension appears twice in the C Coal Mine and D Coal Mine, contributing them to rank first. Furthermore, the A Coal Mine comes out number one in emergency management, and E is in first place in the personnel team. Based on this difference, it is revealed that the five coal mines involved in this paper have their own strengths in the development of emergency response systems for water hazard accidents. As a consequence, it is highly desirable that every coal mine can enhance its accident emergency response capabilities on the basis of the actual situation, together with typical experience and practices.

4.3.2. Determination of Effectiveness Scores and Evaluation of Capability Grades

The calculated comprehensive scores of the emergency response systems for water hazard accidents of the five coal mines are scaled to the range of [0, 1] and graded according to effectiveness levels for emergency response systems of coal mining enterprises in Table 2. These practices aim to identify the corresponding capabilities of the five coal mines (Table 8).

The effectiveness of emergency response systems for water hazard accidents in five coal mines is evaluated comprehensively with a view to identifying their existing weaknesses in emergency response. Furthermore, this paper provides ideas for how to make up for these weaknesses in the hope of urging these coal mines to augment their overall emergency response capabilities.

Table 8. Evaluation table of each dimension index grade of system measurement of coal mine flooding accident.

Symbol	Water Hazard Accidents Emergency Response System Effectiveness (A)	Lv.
A	0.7878	normal
B	0.8131	good
C	0.8002	good
D	0.8412	good
E	0.7964	normal

Symbol	Responsiveness B_1	Lv.	Symbol	Service Capability B_2	Lv.
A	0.7778	normal	A	0.7995	normal
B	0.8270	good	B	0.7969	normal
C	0.8532	good	C	0.8270	good
D	0.8338	good	D	0.7608	normal
E	78.50	normal	E	0.8102	good
Symbol	**Information Transmission C_1**	**Lv.**	**Symbol**	**Command and Control C_2**	**Lv.**
A	0.8280	good	A	0.7902	normal
B	0.8636	good	B	0.8039	good
C	0.8666	good	C	0.8907	good
D	0.8825	good	D	0.7532	normal
E	0.7888	normal	E	0.7985	normal
Symbol	**Rescue and Mitigation C_3**	**Lv.**	**Symbol**	**Emergency Management C_4**	**Lv.**
A	0.7419	normal	A	0.8390	good
B	0.8043	good	B	0.7930	normal
C	0.8086	good	C	0.8372	good
D	0.8431	good	D	0.8390	good
E	0.7689	normal	E	0.7736	normal
Symbol	**Personnel Team C_5**	**Lv.**	**Symbol**	**Prevention of Preparation C_6**	**Lv.**
A	0.7057	normal	A	0.8174	good
B	0.8215	good	B	0.7885	normal
C	0.8286	normal	C	0.8204	good
D	0.7453	good	D	0.7223	normal
E	0.8398	good	E	0.8187	good

5. Conclusions

This paper mainly takes the emergency response ability of coal mine water disaster accidents as the research object. By constructing a comprehensive emergency response evaluation system of coal mine water disaster accidents, the response efficiency of the emergency response system of coal mine enterprises is tested and evaluated, with a view to promote coal mine enterprises in order to improve their own emergency response ability of accidents and disasters and provide references for safe and efficient coal mining and water disaster prevention and management. Firstly, according to the research status at home and abroad, collect data and read a lot of the relevant literature in order to elaborate the characteristics and trends of the current research on water damage in coal mines. Secondly, according to the influencing factors of coal mine water disaster accidents, the literature, and expert suggestions, the evaluation indicators are screened and improved, and the final evaluation index system of coal mine water disaster emergency response efficiency is obtained. Thirdly, the subjective and objective combination weighting model is established by the AHP+ entropy method in order to determine the index weight, and the TOPSIS fuzzy comprehensive evaluation model is derived based on the fuzzy comprehensive evaluation model. Finally, five coal mines under the Coking Coal Group were selected for example analysis, focusing on the evaluation and optimization of the emergency response ability of coal mine water disasters. The main conclusions are as follows:

(1) The efficiency measurement index system of the comprehensive emergency response system for coal mine water disaster accidents can be divided into two parts: normal emergency service capacity and non-normal emergency response capacity, and is then detailed into six secondary indexes, including accident information transmission, emergency command and control, emergency rescue and mitigation, emergency management dimension, personnel team dimension, and prevention and preparedness dimension. It is further divided into 27 three-level indexes, which can avoid the general concept of coal mine accidents and make the evaluation more targeted.
(2) AHP method and entropy method are used to combine and empower the measurement indicators of the emergency response system of water disaster accidents in coal mine enterprises. TOPSIS evaluation model is introduced to build a comprehensive evaluation model of the emergency response ability of water disaster accidents in coal mine enterprises, which avoids too strong subjective thoughts and too simple methods, and enriches the evaluation methods of coal mine accident emergency response ability.
(3) Taking five coal mines under Henan Coking Coal Group as examples, the empirical evaluation of water disaster emergency response system was carried out. According to the evaluation results, the comprehensive evaluation of water disaster emergency response system efficiency of Guhanshan Mine and Zhongma Cun Mine was in "average", while the comprehensive evaluation of water disaster emergency response system efficiency of Jiulishan Mine, Zhaogu No.1 Mine and Zhaogu II mine was in "good". The evaluation results are consistent with the actual situation, indicating that the evaluation model constructed in this paper has good practical significance, can evaluate the efficiency of the emergency response system of water disaster accidents in coal mines scientifically and effectively and provide a new way to improve the efficiency evaluation of the emergency response system of water disaster accidents in coal mines.
(4) To comprehensively evaluate the effectiveness of the emergency response system for water disaster accidents in five coal mines, with the purpose of finding out the deficiencies in the emergency response for water disaster accidents, and taking corresponding rectification measures to improve their overall emergency response capability. Of course, this paper also has some limitations. First of all, there are many factors affecting the emergency response efficiency of coal mine water disaster accidents, so how to scientifically and reasonably select the evaluation index needs further in-depth research. Secondly, there are many evaluation methods for coal mine emergency response capability, and more excellent evaluation methods should be combined. In the future, a more perfect and reasonable evaluation model should be built to continuously optimize and improve.

6. Discussion

Based on the evaluation of the efficacy of the emergency response system for five coal mine water accidents, this paper discusses the following recommendations for rectification:

(1) In the area of accident information transmission, the coal mine water hazard accident source management should be strengthened as far as possible in order to reduce the probability of accidents. Starting from upgrading their abilities to identify hazards, coal mines are encouraged to focus on strengthening their capabilities of predicting water detection and release, as well as on sourcing the causes of water hazard accident, with a view to refining technologies on accident prediction and early warning, reporting accident information more timely, and ensuring the smooth transmission of accident information continuously and effectively. To increase collaboration with

meteorological, water conservancy, flood prevention, and other departments, establish a disaster weather warning and prevention mechanism, pay close attention to the warning information of disaster weather forecasting, timely grasp information on heavy rainfall and flood hazards that may jeopardize the production of coal mines, and take safety precautions. In the meantime, it is also necessary to strengthen information communication with adjacent mines in the surrounding area, when it is found that the water damage of the mine may affect the adjacent mine, an immediate warning is issued to the adjacent mine.

(2) In the emergency command and control, coal mining enterprises are advised to deepen the multidimensional efforts concept and the integrated establishment of water hazard accident underground personnel timely evacuation systems. Greater efforts should be made to enhance the emergency command and control quality of the coal mine personnel, and accelerate the design of scientific and reasonable emergency broadcasting systems. Coal mining should vigorously carry out accident drills, take advantage of safety training, and exchange learning and other opportunities in order to standardize the process steps, such as accident identification and control, emergency command agency activation, disaster relief command coordination, clear start-up criteria, and command departing.

(3) In the emergency relief and mitigation, one should adhere to the "fast, effective, detract" course of action, committed to creating a skilled, rapid action rescue team. With the emphasis of building special and combined emergency rescue teams, set up emergency material reserves and infrastructure emergency temporary deployment points, master rescue technology and equipment, and optimize the current rescue plan. Water damage in coal mines may cause secondary disasters, such as secondary water burst and toxic and harmful gas leakages. Therefore, rescue programs should be systematically built with expert guidance. Perform accident emergency rescue and mitigation work need to pay attention to the combination of peace and war. In other words, the capacity-building of emergency services and the capacity of emergency responses should are both enhanced. What calls for special attention is the operational status of the security monitoring system and the video monitoring system, both of which play an irreplaceable role in guaranteeing the scientificity and effectiveness of emergency rescue and mitigation.

(4) In the emergency management dimension, the emergency response capacity of coal mine water accident mainly depends on the frequency of emergency drills, the scientific nature of emergency preparedness planning and modification drills, the completeness of various systems at all levels, and the proficiency of personnel cooperation. It is recommended that coal mining enterprises organize special drills for water hazards in accordance with the provisions of the "Regulations on Water Prevention and Control" [44] in order to improve the proficiency of material deployment and personnel coordination. Coal mining enterprises are supposed to invest more funds in safety technology based on their actual situation, and establish and optimize management systems of different levels including emergency response systems for water hazard accidents, emergency material reserve management systems, responsibility systems for preventing and controlling water hazard accidents, and water disaster investigation and treatment systems. Besides, it is a must to clarify the responsibilities of the personnel involved with the intention of greatly avoiding disorderly and inefficient emergency response.

(5) In the personnel dimension, coal mining enterprises are expected to increase their knowledge concerning water hazard accidents, clarify a concept of safe development, standardize daily production, and commit themselves to creating a sound situation featuring unified knowledge, belief, and actions for all employees. Set up incentive mechanisms of reward and punishment: employ punishment mechanisms to strengthen the knowledge and skills of personnel in water hazard accidents, and use rewards to inspire employees to learn. At the same time, strengthen the construction

of enterprise safety cultures, cultivate the internal safety motivation of employees, and create a good production safety atmosphere.

(6) In the prevention preparedness dimension, coal mining enterprises should strengthen ties with universities and scientific research institutes, update existing drainage and drainage technology equipment, introduce advanced equipment for mining, monitoring, warning, etc., actively introduce geophysical satellite systems to monitor groundwater flows, and deploy seismic sensors to detect underground bumps. In order to judge groundwater flow and verify the rationality of mine drainage systems, and to improve the graded control ability of underground water hazard risk, all-round improvement of the coal mine water accident detection system and early warning capabilities are desired.

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