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Environmental risk assessment of the middle route of south-to-north water transferring source project in China

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Abstract——This paper focused on the environment risk of the middle route of south-to-north water transferring source project in China. Analytic hierarchy process was applied to risk identification, fuzzy probability-fault tree analysis to risk probability assessment, statistics and analogy process to risk consequences assessment, lastly, grey relevant analysis and comprehensive index process to risk impact evaluation. The main environment risk accident of the project is dam failure, the main causative factors of the accident are catastrophic flood and wrecking earthquake. The flash flood, due to dam failure, will impact on nature, society and economy. The major environment risk areas are Jingzhou and Xiangfan, Hubei Province. The environment risk management measures should be adopted in order to ensure the safety of the project-environment complex system.

Keywords: water source project; environment risk; risk assessment.

1 Introduction

The water conservancy engineering has brought the human society a great economic benefit. When an environment risk (ER) accident occurs in the project-environment complex system, human will be hit by a disasters. Recently, people have paid great attention to this problem.

The environment risk of water conservancy project means the probability and consequences of unexpected event, which occurs on the condition of specific time and space in the project-environment complex system. In this paper, the risk means natural and artificial.

Environment risk should be analyzed in order to manage it scientifically. Environment risk assessment (ERA) includes identification of main risk accident and main causative factors, assessment of accident probability and consequences, and comprehensive evaluation of the environment risk of the complex system. The aim is to provide scientific basis for decision-making.

The middle route of south to north water transferring project is an important project, which will transfer water from the Danjiang Reservoir to the northern of China. This project includes the water source project and transferring water project. The paper focuses on the environment risk of the middle route of south to north water transferring source project.

2 Background

2.1 Environment of water source

Hanjiang River, 1577 km, is the largest tributary of Yangtze River. Danjiang Reservoir sits on the upper-middle reaches of Hanjiang River. It is the best water source of the water transferring project, water quality is good, but the geology condition is complicated. In 1973, the initial stage project of water source led to an earthquake of magnitude up to 4.7.

The middle-lower reaches of Hanjiang River is from Danjiang Reservoir to river mouth, passing across Ebei hillock and Jianghan Plain. The area has 19 cities and towns with population 1.528×10^8, and an annual gross output (industry and agriculture) 4.53×10^{10} RMB Yuan in 1990. The major pollutants are from urban point sources and rural nonpoint sources.

2.2 Survey of water source project

The water source project is to complete Danjiang Reservoir dam construction. The designed regular storage water level of this project is 170m. In 1958, the project began to be constructed according to 170m scheme, but the initial stage project, which is a part of scheme, has only completed. The dam foundation was constructed on the basis of 170m scheme.

The regular storage water level is 157m in the initial stage project of the Danjiang Reservoir, the storage capacity is $1.745 \times 10^{10} m^3$, the altitude of dam top is 162m, total dam length is 2.5 km.

The layout of the completed project is the same as the initial stage project. The altitude of dam top is 176.6m, the regular storage water level 170m, the storage capacity $2.905 \times 10^{10} m^3$. Its principal functions are to control flood, provide water, generate electricity and navigate.

3 Environment risk identification

Because the harm of different environment risk accident is different, and the weight of different factors, which are causative of ER accident, is different, therefore, the environment risk identification (ERI) is necessary. The ERI is an important component of this research, aiming at finding out main ER accident and main causative factors.

3.1 Identification of ER accident

The ER accident of the project includes two types. First, environment subsystem risk accidents caused by the project, such as earthquake, landslide and nonpoint source pollution. Second, project subsystem risk accidents to the environment, such as dam failure and wreck.

Analytic hierarchy process is applied to the identification of ER accident. The major ER accident of the project-environment system is dam failure (Table 1).

Table 1 Weight value of ER accidents

Index	Dam failure	Wreck	Earthquake	Landslide	Pollution
Weight value	0.440	0.220	0.180	0.099	0.054

3.2 Identification of ER causative factors

The factors, which cause dam failure, are major ER causative factors, including natural factors, project factors and social factors.

Analytic hierarchy process is also applied to the identification of ER causative factors, the major ER causative factors of the project-environment system are catastrophic flood and wrecking earthquake (Table 2).

Table 2 Weight value of ER causative factors

Index	Natural factors		Project factors			Social factors	
	Catastrophic flood	Wrecking earthquake	Construction quality	Operation management level	Structure design level	Economic state	War damage
Weight value	0.488	0.244	0.113	0.062	0.034	0.031	0.030

4 Environment risk assessment

The environment risk assessment (ERA) is the critical step of this research. It aims at quantifying ER. The relative and subjective quantity must be applied to ERA, because the objective quantity is limited. The ERA aims of this project are to assess the probability and consequences of the dam failure.

4.1 Probability of dam failure accident

This assessment is significant for comparison of the probability of different water conservancy project. Fuzzy probability-fault analysis tree is applied to assess the probability of ER accident.

Taking dam failure as the top event, causative factors as the elemental event, the Fault Tree is set up.

To quantify natural language, the elemental event probability is expressed with the language aggregate as follow:

$$A = \{\text{largest, large, average, small, smallest}\} = \{A_h\}\ (h=1,\ 2,\ 3,\ \ldots\ldots,5),$$

the limited argument domain is:

$$X = \{X_k\}\ (k = 1,\ 2,\ 3,\ \ldots\ldots,10)\ ,$$

therefore, fuzzy subaggregate can be written as:

$$A_h = \sum_{k=1}^{10} \frac{\mu x_K^{(h)}}{X_K},$$

where, A_h is subordinate to $X_k(X_k \in X)$, $\mu x_k^{(h)}$ is the subordination value of A_h, the fuzzy value of A_h can be counted from the following equation:

$$C_{Ah} = \frac{\sum_{k=1}^{10} \mu x_K^{(h)} \cdot X_K}{N_h},$$

where, N_h is the number of A_h on condition that $\mu x_k^{(h)}$ is not zero.

To quantify the weight value of experts opinion, the experts are asked to assess an elemental event probability on the basis of the natural language aggregate A. Five items and five grades are adopted, the items are weighted through compulsory comparison. The aggregate of items weight coefficient is $\{W_i\}$, the aggregate of grades weigh coefficient is $\{X_{ij}\}$, the score of experts is:

$$A_{ij}^1 = \sum_{j=1}^{5} X_{ij} \cdot B_{il},$$

where i:item array $(i=1,2.\ldots,5)$; j:grade array $(j=1,2,\ldots,5)$;

l:expert array $(l=1,2,\ldots\ldots,15)$;

$$B_{il} = \begin{cases} 1, & \text{the item } i \text{ of expert l is subordinate to grade } j; \\ 0, & \text{the item } i \text{ of expert l is not subordinate to grade } j; \end{cases}$$

the importance value of the opinion of expert l is as follows:

$$R_1 = \sum_{i=1}^{5} A_{ij}^1 \cdot W_i.$$

Thus, the fuzzy probability of elemental event can be estimated from the following equation:

$$P_m = \sum_{i=1}^{15} \sum_{h=1}^{5} R_1 \cdot C_{Ah} \cdot D_{hl}^{(m)},$$

where, m is elemental event array$(m=1,2,\ldots\ldots,32)$;

$$D_{hl}^{(m)} = \begin{cases} 1, & \text{when expert l take the language } \{A_h\} \text{ for elemental event } m; \\ 0, & \text{when expert l does not take the language } \{A_h\} \text{ for elemental event } m. \end{cases}$$

The fuzzy probability of dam failure can be estimated based on the operation law of Boolean algebra, which is 0.0035.

4.2 Impact scope of dam failure accident

The flash flood, due to dam failure accident, must be quantified in order to determine impact scope. Saint Venant equation is adopted as follows:

$$Q_m = \frac{8}{27} \sqrt{g}\, h_0^{3/2},$$

where Q_m is maximum flow volume of flash flood in dam site, m^3/s; g is gravitation acceleration, 9.8 m^2/s; h_0 is water depth in front of dam before dam failure, m.

The maximum flow volume of main section along by the middle-lower reaches of Hanjiang River is given by

$$Q_{xm} = \frac{WQ_m}{W + Q_m XK},$$

where, Q_{xm} is maximum flow volume of main section along by the river when dam failure occurs, m^3/s; W is storage capacity of dam failure, m^3; X is distance from dam site to section along by the river, m; K is coefficient, 0.17; by calculating, Q_m is 4.396×10^6 m^3/s, Q_{xm} is shown as Table 3.

Table 3 Maximum flow volume of main sections along by the middle-lower reaches of Hanjiang River

Section	Nianpanshan	Xingcheng	Zhekou	Dujiatai
X, m	2.70×10^5	3.75×10^5	4.10×10^5	4.96×10^5
Q_{xm}, m^3/s	4.59×10^5	3.41×10^5	3.14×10^5	2.62×10^5
Safety flood discharge, m^3/s	2.7×10^4—3.0×10^4	1.84×10^4—1.9×10^4	1.13×10^4—1.5×10^4	0.52×10^4—0.92×10^4

In 1935, catastrophic flood occurred in Hanjiang River, the maximum flow volume is 5×10^4 m^3/s in Danjiang section, 4.5×10^4 m^3/s in Nianpanshan section. The farmland of 16 cities and towns, 4.3×10^5 ha, was inundated. The victims number was 3.7×10^6 and the number of death people was 8×10^4. Now, the area, along by the middle-lower reaches of Hanjiang River, is provided water with automatic flow, but, the maximum flow volume of dam failure will be larger than in 1935 and safety flood discharge in main section. So, it is easy assumed that the impact area of flash flood will not be smaller than the provided water area, which includes Jingzhou, Xiangfan, Xiaogan and Wuhan districts.

4.3 Consequences of dam failure accident

The consequences of dam failure accident include three respects as follows: First, the economic losses will be heavy. Cities and towns, factories and farmland will be inundated and washed out. Second, the social impacts include injuries and deaths, pestilence spread, and criminal offence and so forth. Third, the ecological impacts include soil salinization and erosion, water pollution, and biological species recession and so on.

The consequences of environment risk accident, which occurs in water conservancy project, are difficult to be assessed. Therefore, the relative and subjective quantity should be used.

Table 4 Impact indices of ER accident

District	Industry losses	Agriculture losses	Injuries and deaths	Pestilence spread	Soil erosion	Water pollution
Xiangfan	0.30	0.11	0.18	0.19	0.09	0.39
Jingzhou	0.46	0.51	0.51	0.46	0.17	0.34
Xiaogan	0.18	0.20	0.27	0.25	0.18	0.03
Wuhan	0.06	0.17	0.04	0.10	0.56	0.26

Obviously, the more public property in the flood area, the more economic losses will be. When the rate of vegetation is small, the rate of soil erosion is large. In this paper, Statistics and Analogy Process are applied to study the consequence. The items include industry losses, agriculture losses, injuries and deaths, pestilence spread, soil erosion and water pollution (Table 4).

5 Environment risk comprehensive evaluation

The probability and consequences of the same ER accidents are different in different area. Therefore, in order to determine the different subsystem's ER, the ER comprehensive evaluation should be made. In this paper, both grey relevant analysis and comprehensive index process are applied.

The data, shown in Table 4, need to be standardized, the method of extreme value standardization is expressed as follows:

$$X'_{ij} = \frac{X_{ij} - \{X_{ij}\}\min}{\{X_{ij}\}\max - \{X_{ij}\}\min},$$

where, X_{ij} is value of item j in district i.

The criterion characteristic reference array is determined with following expression:

$$X_0 = [\max(X'_{i1}),\ \max(X'_{i2}, \cdots\cdots, \max(X'_{i6})].$$

The relevant coefficient can be obtained from the following equation:

$$\S_{i(j)} = \frac{\min\limits_{i}\min\limits_{j} |X_{0j} - X_{ij}| + \rho \max\limits_{i}\max\limits_{j} |X_{0j} - X_{ij}|}{|X_{0j} - X_{ij}| + \rho \max\limits_{i}\max\limits_{j} |X_{0j} - X_{ij}|},$$

where ρ is distinguishing coefficient, here ρ is 0.5 in the case.

The relevant value is shown as follows:

$$W_i = \frac{1}{n} \sum_{j=1}^{n} \S_{i(j)}$$

$$(i = 1, 2, \cdots\cdots 4;\ j = 1, 2, \cdots\cdots 6)$$

According to the definition of ER, the index of ER can be written as follows:

$$R_i = P \cdot U_i \cdot W_i,$$

where P is fuzzy probability of dam failure; U_i is responsory coefficient of different district, here U_i is 1.0; W_i is relevant value is applied to express impact.

The comprehensive evaluation result of different district is shown in Table 5. It is shown that the ER of Jingzhou and Xiangfan district is great.

Table 5 Outcome of ER comprehensive evaluation

District	Jingzhou	Xiangfan	Xiaogan	Wuhan
ER index	0.40	0.26	0.18	0.16

6 Conclusion and suggestion

6.1 Conclusion

From the environment risk assessment, the following conclusion can be made: The main ER accident of the project is dam failure. The main causative factors, which cause dam failure, are catastrophic flood and wrecking earthquake. The ER accident will have tremendously adverse impacts on nature, society and economy. The major ER-effected areas are Jingzhou and Xiangfan districts.

6.2 Suggestion

Although the ER of the project have been considered in the course of design, construction and management, in order to ensure the safety of the project-environment complex system, the ER management measures should be adopted as follows: to establish the management organization of the middle route of south-to-north water transferring source project; to enforce the ER management in the course of design, construction and operation; to rationally plan the economic development on the middle-lower reaches of Hanjiang River; to strengthen the construction of flood control works in the middle-lower reaches of Hanjiang River; to set up the risk prediction system of the project-environment complex system; to take emergency measures promptly when dam fail.

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