Risk analysis of floodwater resources utilization along water diversion project: a case study of the Eastern Route of the South-to-North Water Diversion Project in China

Guohua Fang, Xiaohua Zhu and Xianfeng Huang

ABSTRACT

Based on fuzzy mathematics, a risk assessment model of floodwater resources utilization in a water diversion project was established based on the fuzzy network analytic hierarchy process (F-AHP). First, the weight of each factor was determined through AHP, and then the fuzzy evaluation method (FEM) was used for analysis and comparison. Finally, the optimal decision scheme was determined. The model was applied to the Eastern Route of the South-to-North Water Diversion Project (SNWDP) for floodwater resources utilization risk assessment. The results show that the model can utilize the risk factors of floodwater resources for identification and sorting, and then make a risk evaluation. The risk of floodwater resources utilization in a normal flow year is the lowest and the benefit is remarkable, providing a reasonable control scheme, and reducing unnecessary losses for the risk of floodwater resources utilization.

Key words | F-AHP, floodwater resource utilization, risk analysis, south to north water diversion project

Guohua Fang (corresponding author)
Xiaohua Zhu
Xianfeng Huang
Water Resources Department of Jiangsu Province, Nanjing 210098, China
and
College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing 210098, China
E-mail: *hhufgh@163.com*

INTRODUCTION

There are serious problems of uneven distribution of water resources between the north and the south of China. However, with the rapid development of China's social economy and the continuous expansion of the population, the overall water demand is growing rapidly, and the contradiction between water supply and demand of water resources in many regions will be more and more prominent. It has inspired further exploration of the way that water resources are utilized. The use of floodwater resources is to further tap the potential of floodwater resources that have been difficult to use in the past on the basis of the general development and utilization of water resources. Since water diversion projects are generally carried out in non-flood seasons, if the floodwater resources in flood seasons are fully utilized, the situation of water resources shortage in North China will be greatly reduced and further alleviated. Strengthening the utilization and management of floodwater resources can improve the utilization rate of water resources in water diversion projects and bring huge economic benefits along the water diversion projects. However, floodwater resources have dual attributes, bringing benefits and risks at the same time. In order to rationally develop and safely utilize floodwater resources, it is necessary to carry out risk analysis on the utilization of floodwater resources.

At present, there are few studies on the utilization of floodwater resources, which are mainly on flood risk, flood disaster and loss. Paik (2008) adopted the mean first-order second-moment method and the improved first-order second-moment method to calculate the risk of flood storage and detention area. Hu & Wang (2009) proposed a floodwater resources utilization evaluation method that can ensure flood control safety; Wang *et al.* (2015) analyzed the

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appropriateness of floodwater resources utilization by using different frequency design floods. Brenner *et al.* (2016) integrated orthophoto images into flood risk analysis, so that risk losses can be evaluated regularly. Wang *et al.* (2017) evaluated the potential risks and benefits of floodwater resources in the basin. Su *et al.* (2018) proposed a multi-objective optimization design framework for flood risk management based on elastic objectives and applied it to the basin of Indonesia.

Studies on risk assessment of floodwater resources utilization mainly focus on reservoir floodwater resources utilization (Zou *et al.* 2018), basin floodwater resources utilization (Wu *et al.* 2016) and regional floodwater resources utilization (Di 2016), and there are few evaluation systems for floodwater resources utilization of water diversion projects. Li *et al.* proposed a risk assessment system for the utilization of floodwater resources in water diversion projects. However, this system only considers engineering risks, while the utilization of floodwater resources is a complex process. Therefore, this paper takes the Eastern Route of the SNWDP as an example, establishes a risk assessment model by using the fuzzy network analytic hierarchy process, and carries out risk analysis on floodwater resources utilization in three typical years of wet–flat–dry from three aspects of engineering risk, water quality risk and dispatching risk.

RESEARCH METHOD

Research area

The first phase of the Eastern Route of the SNWDP will expand its scale and extend to the north on the basis of the North Water Diversion Project in Jiangsu Province. The water diversion line starts from the main stream of the Yangtze River near Yangzhou, Jiangsu Province (Figure 1).

The emergency Yellow River diversion line of the first phase of the Eastern Route has been connected, which is capable of carrying water to Hebei Province and Tianjin.

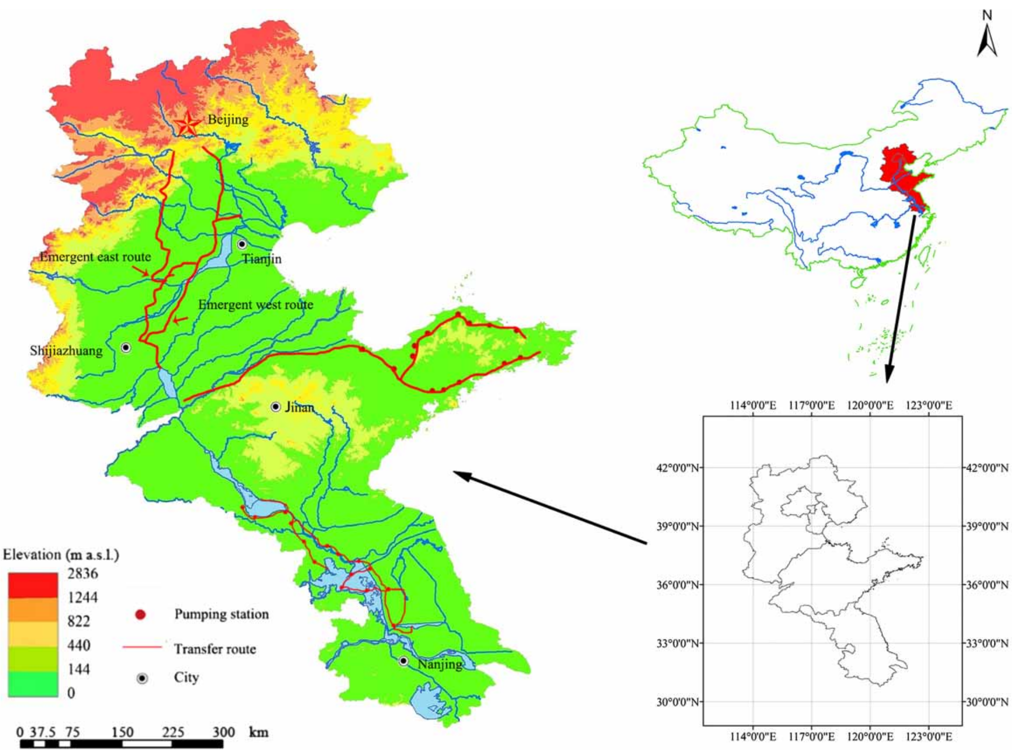

Figure 1 | Schematic diagram of emergency water supply line extending from the Eastern Route of the SNWDP to the north. It will carry water to the north along the Beijing–Hangzhou Grand Canal and its parallel channels. In addition, the water will be delivered to the eastern part of Jiaodong Peninsula along the way, with a total length of 1,466.50 km (Chen *et al.* 2018).

Before the implementation of the second phase, on the basis of using a phase of the water conveyance capacity, consideration is given to increasing the use of floodwater resources, joint scheduling management and adding a small amount of engineering measures, full excavation and the potential of water resources, using the time of year and emergency water to the north of three provinces (municipalities directly under the central government) of the Beijing–Tianjin–Hebei region, to realize the rational utilization of water resources and allocate, giving play to the greatest benefit of the first phase. In order to rationally develop and safely utilize floodwater resources, it is necessary to analyze the risk of floodwater resources utilization. Figure 1 shows the location diagram of the emergency water supply line extending northward on the Eastern Route of the SNWDP.

General steps for risk analysis

Risk analysis is to avoid or reduce losses, identify the risk factors in the program, and analyze their nature, impact and consequences, so as to provide a basis for decision makers. Its basic flow is: risk identification → risk assessment → risk prevention.

Risk identification

Risk identification is the primary task of risk analysis. Risk identification is the systematic understanding and analysis based on reliable information to determine what kind of risk the project presents. Through the identification of risks, the main factors causing these risks can be found, the characteristics of various risk factors can be analyzed, and the main factors can be screened out according to their influence degree, so as to find out the main risk factors and take targeted measures.

Risk assessment

Risk assessment is based on risk identification, through the corresponding index system and evaluation criteria. The risk degree is divided, with the probability of the occurrence of various risks and the possible loss size, revealing the key risk factors affecting the success or failure of the project, and preventive measures are taken against the key risk factors.

Risk prevention

Risk prevention is to prevent the occurrence of risk loss by planning, organizing, controlling and checking purposefully and consciously, so as to weaken the influence degree of loss occurrence and obtain the maximum benefit.

RESEARCH DESIGN AND PROCESS

Based on fuzzy mathematics and combined with the analytic hierarchy process (AHP), this paper establishes a risk evaluation model of floodwater resources utilization (F-AHP) along a water diversion project based on F-ANP (fuzzy analytic network process). The first step of floodwater resources utilization in a water diversion project is risk identification, then establishing a risk evaluation system, using Super Decisions software for floodwater resources utilization along the water transfer project risk evaluation index system for weight calculation, finally calculating the index weight in the fuzzy comprehensive calculation, according to expert division level to evaluate the results.

Identification of floodwater resources utilization risk in a water diversion project

According to the opinions of Sun (2014) on AHP and ANP (analytic network process), AHP is a decision-making method aiming to solve multi-objective problems quantitatively by simulating the judgment thinking mode of human beings in dealing with complex decision-making problems. When using AHP to solve a problem, the first step is to divide the factors related to the problem into a target layer, criterion layer and scheme layer. The second step is to judge the relationship between different levels. The importance of each factor is compared by means of expert scoring. The relative importance of each scheme is calculated under different criteria. Finally, the scheme is sorted and the optimal choice is obtained. AHP embodies the decision-making thinking of human beings and obviously improves the decision-making efficiency.

ANP is a decision-making method which has been gradually developed from AHP and is suitable for more complex structure. ANP, because of its more complex network structure, and skillfully combining the structure to hierarchical form, internal dependence and feedback, effectively weakens the subjective role of AHP. The factors are interrelated and affect each other, forming a typical ANP structure, as shown in Figure 2.

The purpose of the utilization of floodwater resources is to increase the amount of available water resources and promote the sustainable development of economy and society. After theoretical analysis and expert consultation, the risk factor identification system is divided into three levels, including target level, criterion level and indicator level, by using AHP. The evaluation system of the rule layer includes three aspects: project risk, risk of water quality and scheduling, index layer, and a total of ten indicators, which respectively are: the risk of impounded water level exceeding the warning water level, the risk of gate station maintenance failure, the risk in case the pump station cannot drain properly, the risk of exceeding the design condition of the gate station, the risk of river channel level exceeding the warning level, the risk of water quality contamination in intake areas, the risk of water quality contamination during the water transfer process, the risk of ecological problems caused by poor water quality, the risk of uncoordinated dispatching management and the risk of impassability of the emergency water transfer route. The hierarchical structure is shown in Figure 3.

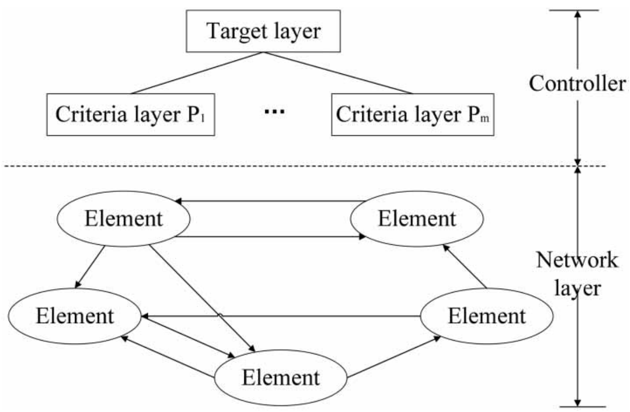

Figure 2 | The typical structure diagram of ANP.

Risk assessment model of floodwater resources utilization in water diversion project based on F-ANP

Index weight calculation

This paper adopts Super Decisions software to calculate index weight. Firstly, the network relationship among

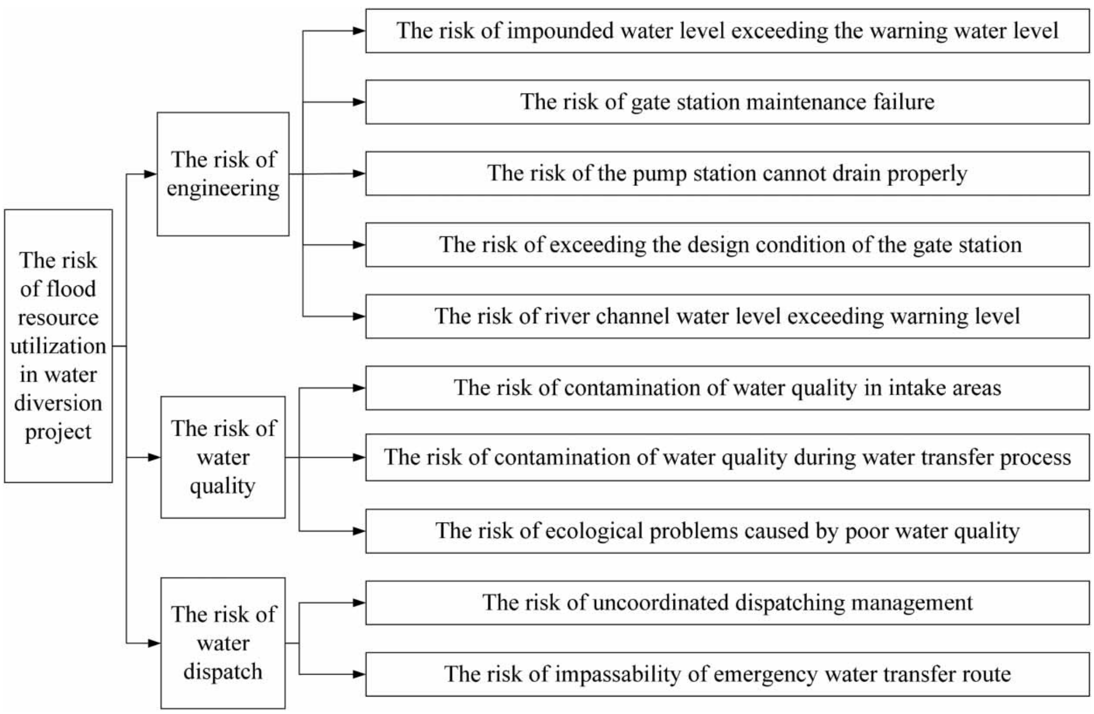

Figure 3 | Hierarchical structure of risk factors for the utilization of floodwater water resources in a water transfer project.

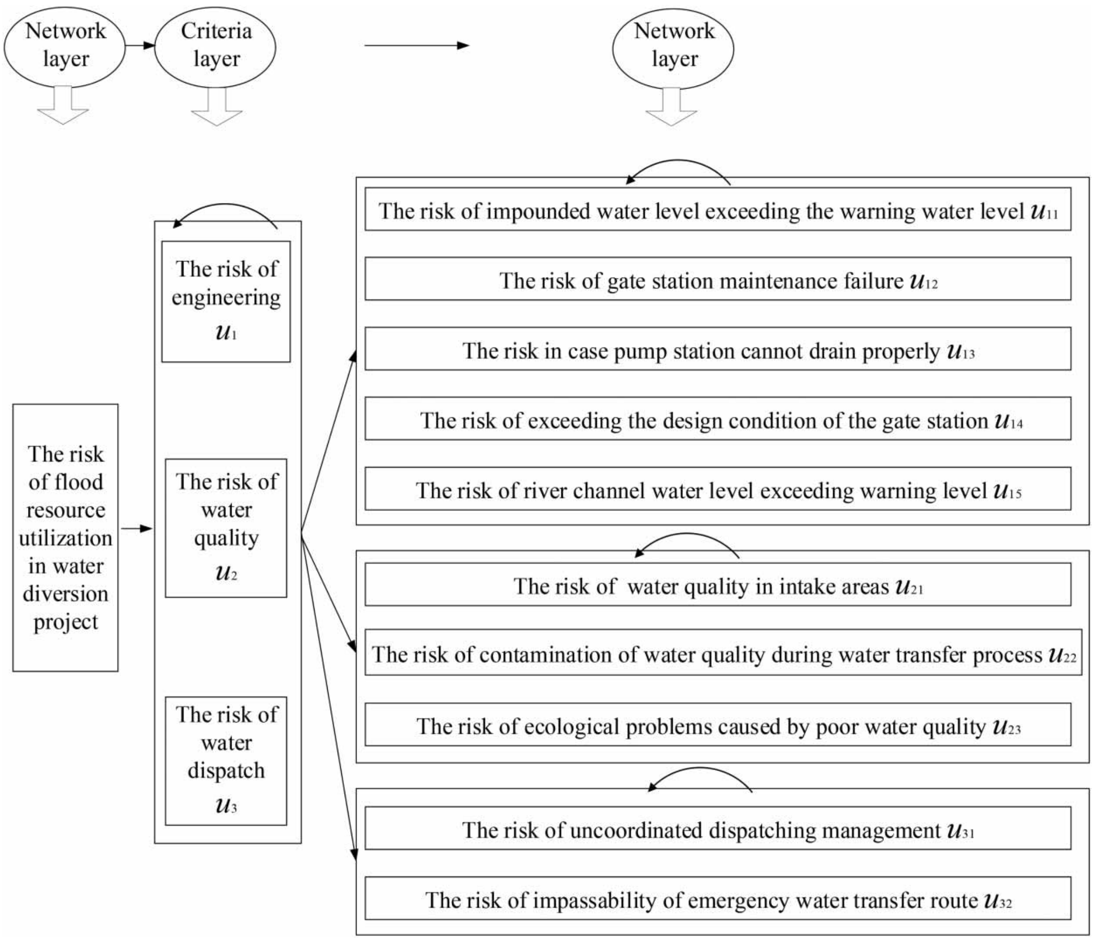

Figure 4 | Structure diagram of ANP in Super Decisions.

evaluation index factors is established in the software according to the logical hierarchical relationship (as shown in Figure 4). For example, 'criterion layer sub-criterion layer' indicates that the latter index factors affect the former index factors, while the arched arrow indicates that internal nodes depend on and influence each other. ANP uses a 1–9 scale method to judge the importance degree of each factor index in pairs (see Table 1 for the meaning of the 1–9 scale).

In order to ensure the accuracy of each factor index, it can be selected to summarize the opinions of several experts with feedback to them again, to modify the ones with big differences, so as to reach the final consensus, and make the judgment matrix constructed meet consistency in the test. Considering the ANP index factors' mutual influence, so indirect dominance comparison should be carried out (under the standard of the two elements of a given standard to determine the importance of the third element), and comprehensive consideration of various factors, respectively

Table 1 | The meaning of the 1–9 scale

Scale	Meaning (the comparison between two elements)
1	Of equal importance
3	The former is slightly more important than the latter
5	The former is significantly more important than the latter
7	The former is more important than the latter
9	The former is far more important than the latter
2,4,6,8	The intermediate values of the above neighboring judgments

under different time rule layers, so as to make the final weight more consistent with the actual. Finally, the local weight super-matrix $\boldsymbol{W}$ of index elements in all sub-criterion layers is constructed, then a weighted matrix **A** is constructed according to the weights between the criterion layers, to find the weighted super-matrix $\overline{\boldsymbol{W}}$, and according to the weighted super matrix obtained, the vector with the eigenvalue of 1 is obtained, that is, the final weight of each index factor.

Steps of the risk assessment model

The evaluation model of floodwater resources utilization risk along the water transfer project based on F-ANP is a kind of multi-factor decision method using fuzzy sets to conduct a comprehensive evaluation, such as Lu *et al.* (2014) carried out on the runway invasion risk fuzzy evaluation based on ANP. This method is applied to the risk assessment system of floodwater resources utilization along the water diversion project. Many index factors affecting the system are taken into account comprehensively, and the fuzzy matrix is established. The weight result calculated by ANP is substituted into the fuzzy operation, and the comprehensive evaluation result is finally obtained. According to the theory, method and application of multi-objective decision-making (Fang & Huang 2011), the model is established. The specific steps are as follows:

(1) Determinate factor set $\boldsymbol{U} = \{u_1, u_2, \ldots, u_n\}$, in which $u_i (i = 1, 2, \ldots, n)$ stands for the ith factor that influences the evaluation value.

(2) Determine the factor evaluation set $\boldsymbol{V} = \{v_1, v_2, \ldots, v_m\}$, in which $v_j (j = 1, 2, \ldots, m)$ stands for the jth grade that affects the evaluation value.

(3) Single-factor judgment determines the membership degree of each factor for each evaluation grade. Since the floodwater resources utilization risk factors along the water diversion project in this paper are all qualitative indicators, the membership degree determination method of qualitative indicators (such as expert scoring method, field survey method, etc.) is adopted here to give the criterion layer and sub-criterion layer of the risk. Through the above steps and methods, the membership degree r_{ij} of the qualitative index can be obtained in Equation (1), and then the evaluation matrix $\boldsymbol{R}$ can be obtained:

$$\boldsymbol{R} = (\boldsymbol{R}_1, \boldsymbol{R}_2, \ldots, \boldsymbol{R}_n)^{\mathrm{T}} = (r_{ij})_{n\times m} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} \quad (1)$$

(4) The weight of each factor $\boldsymbol{W} = (\omega_1, \omega_2, \ldots, \omega_n)$ is determined by the above network AHP. $\boldsymbol{W}$ represents the significance of u_i in the evaluation. In general, $0 < \omega_i < 1$, $\sum_{i=1}^{n} \omega_i = 1$.

(5) Comprehensive evaluation. Firstly, choose the composition operator, then put $\boldsymbol{W}$ and $\boldsymbol{R}$ in the fuzzy calculation, and the final judgment can be made on the evaluated object through further analysis. The specific flow chart is shown in Figure 5.

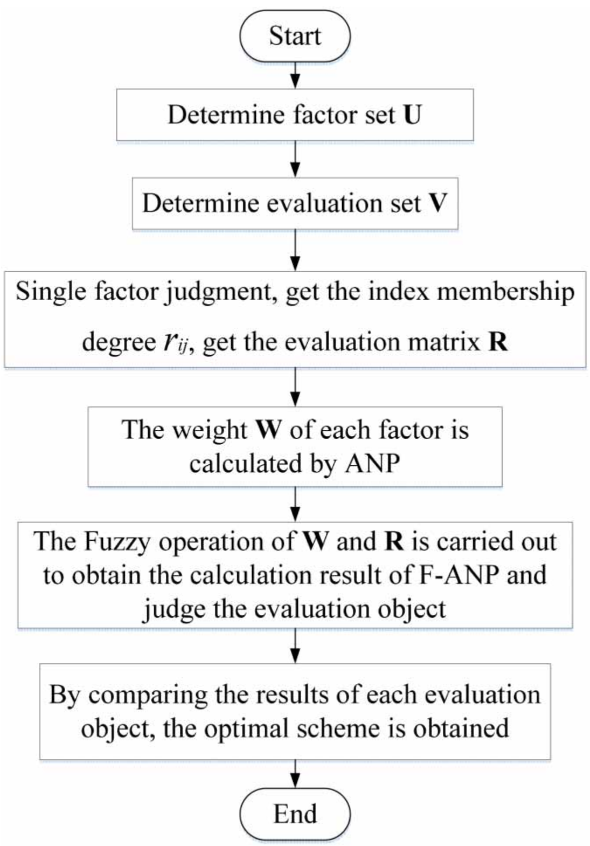

Figure 5 | The flow diagram of the F-ANP model.

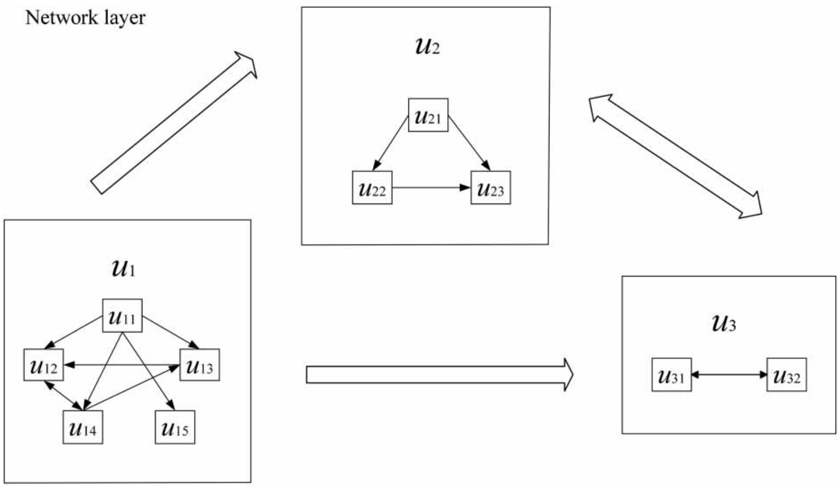

Figure 6 | Network level analysis diagram for risk of utilization of floodwater in water transfer project.

Experiment setting

Using ANP to determine index weight

Super Decisions software was used to establish the network level analysis diagram (as shown in Figure 6) according to the actual logical relationships. In each group of elements, a dominance comparison is carried out, and the judgment matrix is established and tested for consistency based on the collection and processing of expert scoring results. The judgment matrix is determined to be accepted or not based on the test results. In the criterion layer of the risk indicator system, if the consistency test result of the indicator judgment matrix is less than 0.1, the judgment matrix is accepted and the weight of each index is given at the same time. Similarly, the weight of each guideline layer can be generated, and finally clicking the Computations option in the drop-down menu of the Super Decisions software can generate the final weighted weight, and then obtain the weighted super-matrix $\overline{\boldsymbol{W}}$.

The risk comparison judgment matrix of the criterion layer of the evaluation index system is constructed through the SD software, as shown in Table 2.

The characteristic roots of the judgment matrix $\lambda_{\max} = 3.0324 > n = 3$ can be obtained from Table 2. The corresponding eigenvector is $\boldsymbol{W}_1 = (1.5874 \quad 1.7100 \quad 0.3684)$, and the normalized eigenvector is $\boldsymbol{W'}_1 = (0.4330 \quad 0.4665 \quad 0.1005)$. The random consistency ratio of the judgment matrix is calculated as $\boldsymbol{CR}_1 = 0.0048 < 0.1$, and the judgment matrix meets the consistency requirement.

Table 2 | Comparison judgment matrix of criterion layer risk

	u_1	u_2	u_3
u_1	1	1	4
u_2	1	1	5
u_3	1/4	1/5	1

For all kinds of risk factors in the index layer of the evaluation index system, the relative weight of five risk factors in the engineering risk index layer, three risk factors in the water quality risk index layer and two risk factors in the scheduling risk index layer were calculated respectively, and the absolute weight of each risk factor was finally calculated. The comparison and judgment matrix of the engineering risk index layer is shown in Table 3, and the comparison and judgment matrix of the water quality risk

Table 3 | Comparison judgment matrix of the engineering risk index layer

	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}
u_{11}	1	3	1/2	1/3	4
u_{12}	1/3	1	1/3	1/5	2
u_{13}	2	3	1	1/2	5
u_{14}	3	5	2	1	7
u_{15}	1/7	1/2	1/5	1/7	1

Table 4 | Comparison and judgment matrix of the water quality risk index layer

	u_{21}	u_{22}	u_{23}
u_{21}	1	1/6	2
u_{22}	6	1	7
u_{23}	1/2	1/7	1

index layer is shown in Table 4. Since the scheduling risk only contains two risk factors, its weight value is directly calculated based on the expert evaluations of these two risks, which are 0.80 and 0.20 respectively.

The characteristic roots of the judgment matrix $\lambda_{\max} = 5.0773 > n = 5$ can be obtained from Table 3. The corresponding eigenvector is $\boldsymbol{W}_2 = (1.1487 \quad 0.5365 \quad 1.7188 \quad 2.9137 \quad 0.3240)$, and after normalization, the eigenvector is $\boldsymbol{W'}_2 = (0.1746 \quad 0.0807 \quad 0.2584 \quad 0.4377 \quad 0.0486)$. The random consistency ratio of the judgment matrix is calculated as $\boldsymbol{CR}_2 = 0.0171 < 0.1$, and the judgment matrix meets the consistency requirement.

The characteristic roots of the judgment matrix $\lambda_{\max} = 3.0324 > n = 3$ can be obtained from Table 4. The corresponding eigenvector is $\boldsymbol{W}_3 = (0.6934 \quad 3.4760 \quad 0.4149)$, and after normalization, the eigenvector is $\boldsymbol{W'}_3 = (0.1512 \quad 0.7582 \quad 0.0905)$. The random consistency ratio of the judgment matrix is calculated as $\boldsymbol{CR}_3 = 0.0279 < 0.1$, and the judgment matrix meets the consistency requirement. The total sorting of the layers is calculated from the top to the bottom by the method of probability multiplication, and the sum of the weight values of the total sorting of each layer is 1. The absolute weight value of the ten indicators in the calculation index layer is:

$$\overline{\boldsymbol{W}} = \begin{pmatrix} 0.0756 & 0.0349 & 0.1119 & 0.1895 & 0.0210 & \ldots \\ \ldots & 0.0705 & 0.3408 & 0.0378 & 0.0804 & 0.0201 \end{pmatrix}$$

The weight values of each index layer obtained through the judgment matrix are shown in Table 5.

The main risk factors for the utilization of floodwater resources on the Eastern Route of the SNWDP can be determined from the evaluation results of the network hierarchy analysis: (1) the risk of water quality being polluted in the process of the SNWDP (0.3408); (2) the risk that the brake station exceeds the design condition (0.1895); (3) the risk of the failure of the pumping station to discharge waterlogging normally (0.1119); (4) the risk of uncoordinated scheduling management among departments (0.0804); (5) the risk of water storage making the lake water level exceed the warning level (0.0756). The sum of the absolute weight of the five risk factors is 0.8046, which

Table 5 | Weight values of different risk factors

The target layer	**The criterion layer**	**The index layer**	**Absolute weight value**
Identification of floodwater resources utilization risk factors on the Eastern Route of the SNWDP	Risk of the project u_1 (0.4330)	The risk of impounded water level exceeding the warning water level u_{11} (0.2829)	0.0756
		The risk of gate station maintenance failure u_{12} (0.0649)	0.0349
		The risk of the pump station not draining properly u_{13} (0.1422)	0.1119
		The risk of exceeding the design condition of the gate station u_{14} (0.4676)	0.1895
		The risk of river channel level exceeding warning level u_{15} (0.0424)	0.021
	Risk of the water quality u_2 (0.4665)	The risk of contamination of water quality in intake areas u_{21} (0.1512)	0.0705
		The risk of contamination of water quality during water transfer process u_{22} (0.7582)	0.3408
		The risk of ecological problems caused by poor water quality u_{23} (0.0905)	0.0378
	Risk of the regulation u_3 (0.1005)	The risk of uncoordinated dispatching management u_{31} (0.8000)	0.0804
		The risk of impassability of emergency water transfer route u_{32} (0.1000)	0.0201

accounts for a large proportion. In risk prevention, preventive measures should be proposed for these risk factors.

Calculation results of the evaluation model based on F-ANP

Firstly, a fuzzy evaluation matrix is constructed according to the expert group's evaluation of the indicators, as shown in Table 6, in which the indicator evaluation set of the risk is divided into five risk levels from low to high, $\boldsymbol{V} = \{v_1, v_2, \ldots, v_m\} = \{\text{I, II, III, IV, V}\}$.

Then the weight of each index and the fuzzy matrix are substituted into the calculation as seen in Equation (2):

$$\boldsymbol{B}_i = \overline{\boldsymbol{W}} \delta \boldsymbol{R}_i = (b_{i1} \quad b_{i2} \quad \ldots \quad b_{im}) \quad (1 \le i \le 3)(m = 5) \qquad (2)$$

in which δ is the fuzzy synthesis operator, representing the synthesis operation of the fuzzy matrix. The weighted average fuzzy synthesis operator is adopted here, the calculation formula is $b_m = \sum_{j=1}^{10} \omega_j r_{jm}$, and the results of the fuzzy comprehensive evaluation are shown in Table 7.

According to the principle of maximum membership, from $\boldsymbol{B}_{1max} = 0.3869$, $\boldsymbol{B}_{2max} = 0.3596$, $\boldsymbol{B}_{3max} = 0.4751$, we can know that the risk level in the high flow year is III, corresponding to medium risk, while the risk levels in the normal flow year and the low flow year are II and I, corresponding to low risk and relatively safe. It can be found from the risk level of specific indicators that there are many level-III risk indicators in the normal flow year, while there are level-II or level-I risks in the low flow year, which further indicates that the floodwater resources utilization risk in a dry year is the lowest. The evaluation result of this paper is consistent with the expert evaluation, which indicates that the F-ANP has good adaptability to the risk evaluation.

According to the cost–benefit table of floodwater resources utilization of the Eastern Route (as shown in Table 8) in the special study on the coordination of 'The preliminary work of SNWDP', the net benefits of water diversion in the high–normal–low flow years of the project are 3.62 yuan/m^3, 3.28 yuan/m^3 and 2.76 yuan/m^3. Considering the analysis of the different risks and efficiencies of the typical model of the utilization of floodwater resources by the water transfer project and its possible problems: floodwater is rich in the high flow year, there are enormous adjustable floodwater resources that can be transferred to the Beijing–Tianjin–Hebei region, but the risk of floodwater resources utilization is relatively high, and the amount of water deficiency is smaller than in the normal flow year and the benefit is not significant. The amount of adjustable floodwater resources in a normal year is moderate, the risk of floodwater resources utilization is low, the water shortage is large, and the floodwater resources utilization benefit is high.

Table 6 | Fuzzy evaluation matrix

Fuzzy evaluating matrix	I	II	III	IV	V
High flow year $\boldsymbol{R}_1$	0	0.2	0.6	0.15	0.05
	0.1	0.7	0.2	0	0
	0.1	0.6	0.3	0	0
	0.6	0.3	0.1	0	0
	0	0.1	0.75	0.1	0.05
	0.2	0.4	0.3	0.1	0
	0.2	0.2	0.5	0.1	0
	0.2	0.2	0.5	0.1	0
	0.2	0.3	0.4	0.1	0
	0.3	0.5	0.2	0	0
Normal flow year $\boldsymbol{R}_2$	0.2	0.6	0.15	0.05	0
	0.6	0.4	0	0	0
	0.6	0.4	0	0	0
	0.7	0.3	0	0	0
	0.15	0.75	0.1	0	0
	0.2	0.4	0.3	0.1	0
	0.2	0.2	0.5	0.1	0
	0.2	0.2	0.5	0.1	0
	0.3	0.7	0	0	0
	0.4	0.6	0	0	0
Low flow year $\boldsymbol{R}_3$	0.7	0.25	0.05	0	0
	0.7	0.3	0	0	0
	0.8	0.2	0	0	0
	0.85	0.15	0	0	0
	0.15	0.75	0.1	0	0
	0.2	0.4	0.3	0.1	0
	0.2	0.2	0.5	0.1	0
	0.2	0.2	0.5	0.1	0
	0.5	0.5	0	0	0
	0.6	0.4	0	0	0

Table 7 | Risk assessment of floodwater resources utilization on the Eastern Route of the SNWDP in different typical years

	Degree of membership					
Typical year	I	II	III	IV	V	Level
High flow year	0.2459	0.2853	0.3869	0.0749	0.0070	III
Normal flow year	0.3482	0.3596	0.2394	0.0528	0.0000	II
Low flow year	0.4751	0.2512	0.2271	0.0467	0.0000	I

Table 8 | Cost–benefit table of floodwater resources utilization on the Eastern Route of the SNWDP

	Multi-year average	High-flow-year average	Normal-flow-year average	Low-flow-year average
Overall regulation (hundred million m^3)	1.98	2.89	2.46	1.12
The cost of water supply (hundred million yuan)	4.77	5.82	4.86	3.64
Cost per cubic metre of water supply (yuan/m^3)	2.41	2.01	1.98	3.25
Overall benefit (hundred million yuan)	11.03	16.27	12.92	6.73
Benefit of water supply per cubic metre (yuan/m^3)	5.57	5.63	5.25	6.01
Net benefit of water supply per cubic metre (yuan/m^3)	3.16	3.62	3.28	2.76

Although the regulation risk in the low flow year is low, the water abandoned in the flood season is little, and the adjustable floodwater resources are few, resulting in the lack of guarantee of water supply. To sum up, in order to take into account both benefits and risks, it is the safest choice to utilize floodwater resources on the Eastern Route of the SNWDP in a normal year, as shown in Table 8.

RISK CONTROL

The main risk factors in the utilization of floodwater resources on the Eastern Route of the SNWDP are:

(1) the risk of water quality being polluted in the process of the SNWDP;
(2) the risk that the brake station exceeds the design condition;
(3) the risk that the pumping station cannot discharge waterlogging normally;
(4) the risk of uncoordinated scheduling management among various departments;
(5) the risk of water storage exceeding the warning level of the lake water level.

Therefore, this paper proposes the following five measures to prevent the risk of the five major factors.

Prevention of water pollution

The Eastern Route of the SNWDP is an important drinking water transportation route in the Beijing–Tianjin–Hebei region. Differently from general environmental pollution, sudden environmental pollution events have no fixed pollution discharge mode or way. To deal with such pollution events, an efficient emergency management system and a quick response team are required. Therefore, the following four measures are proposed: (1) strengthen the management of dangerous goods transportation; (2) establish a sound early-warning and monitoring system for sudden pollution incidents; (3) establish a sound emergency management system; (4) improve emergency monitoring levels.

Improve monitoring technology

Lakes and pumping stations should be strictly managed, making use of modern monitoring technology, scientific flood control project planning and safety monitoring cycles should be formulated, and the operation mode of the Eastern Route of the SNWDP should be optimized. As flood control increases the operation time of the project, a comprehensive and thorough engineering inspection should be carried out on a regular basis. The main contents of the inspection include: channels, buildings, electromechanical equipment, power supply, communication, flow measurement, safety measures, etc. The inspection situation should be reported on the spot, and the problems found should be rectified within a specified period.

Ramp up river embankments

A large amount of rainfall will lead to the rise of the water level in the downstream river. If the current is rapid, it is easy to collapse the river bank, forming a flood, with difficulty in estimating the loss. Therefore, river governance is an important measure to protect people's safety and interests. River management can be carried out in the following aspects: regular dredging of the blocked river; widening the section of the river with insufficient section; straightening sections of rivers with large local twists and turns, to make substandard river courses up to the standard as required; reinforcing and raising dikes.

Strengthen scheduling management

The construction of the emergency water supply dispatching management mechanism of the Eastern Route of the SNWDP is based on the macro-leadership of the government and with reference to market operation, so as to gradually realize the enterprise management, ensuring the scientific and standardized emergency water supply dispatching management of the Eastern Route of the SNWDP, and thus solving the problem of water supply difficulty in the north. The relevant functional departments of the Eastern Route of the SNWDP should coordinate all kinds of relations, aiming at making full use of water resources, so as to better achieve the set water supply goals.

Strengthen flood forecasting

The purpose of flood forecasting is to utilize flood forecasting information to realize floodwater resources utilization. Under the premise of assuming certain risks, a more economical and effective water storage plan should be made to improve the efficiency of the utilization of floodwater resources by making use of the predicted flood evolution trend. In the dispatching process, due to the uncertainty of incoming water, lake flood control dispatching has some risks. Therefore, it is necessary to establish a perfect forecasting and early warning system, strengthen the monitoring of real-time lake water level, and conduct real-time dispatching to ensure that the lake water level is within a safe and controllable range.

CONCLUSION

Risk analysis is an essential step in floodwater resources utilization. Through risk analysis, appropriate measures should be taken to increase the security and controllability of water resources utilization under the lower disaster risk. The risk analysis of floodwater resources utilization is carried out according to the steps of risk identification, risk assessment and risk prevention.

The utilization of floodwater resources can alleviate the problem of water resources shortage in China to a certain extent. Rational use of floodwater resources should control the risk within a certain range and take risk avoidance measures when necessary. In this paper, a risk index system for the utilization of floodwater resources along the water diversion project is constructed, and the subjective and objective combination weights are calculated by using AHP. Based on fuzzy mathematics theory, the membership degree is calculated to evaluate the utilization risks of floodwater resources along the water diversion project. Through the calculation and analysis of the Eastern Route of the SNWDP, it can be found that the risk is the highest and the benefit is relatively higher in the wet year, the risk is lower in the flat year and the benefit is similar to that in the wet year, and the risk is the lowest in the dry year, but the benefit is the lowest. Along the water transfer project, risk assessment of floodwater resources utilization is equipped with the practical significance of floodwater resources security using, at the same time, floodwater resources utilization of the Eastern Route. The Beijing–Tianjin–Hebei region is of great economic and social significance and the risk evaluation method based on fuzzy network AHP for flood diversion projects provides an important theoretical support of safety resources utilization, and the Eastern Route of the SNWDP floodwater resources utilization has important reference value.

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