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RESEARCH ARTICLE

Comprehensive risk assessment of algae and shellfish in the middle route of South-to-North Water Diversion Project

Yan Long[1,2] · Mengjuan Feng[1,2] · Youming Li[1,3] · Jia Qu[1,2] · Wei Gao[1,2]

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Abstract
Since the main canal of the middle route of South-to-North Water Diversion Project was put into operation, the species, quantity, and biomass of algae and shellfish have responded quickly to the environment, and a single dominant species has appeared in the community, demonstrating the remarkably abnormal proliferation property of algae and shellfish. In order to evaluate the safety risk of abnormal proliferation of algae and shellfish in the middle route and realize dynamic analysis of all kinds of influencing factors, a comprehensive risk evaluation system of algae and shellfish in the middle route of South-to-North Water Diversion Project based on comprehensive weighting and four-element connection number was constructed by integrating the analytic hierarchy process (AHP) and the weight assignment theory of criteria importance through intercriteria (CRITIC). The system consists of 21 evaluation indexes selected from risk factors and carriers. Taking Henan section in the middle route as an example, comprehensive risk evaluation system of algae and shellfish in the middle route of South-to-North Water Diversion Project was applied to calculate the partial connection number of each order and obtain the risk development trend of each indicator. The results showed that algae and shellfish in the middle route were in a very safe state at the safety risk level of level I. Finally, reasonable measures to reduce the risks facing algae and shellfish in the middle route of South-to-North Water Diversion Project are given, which effectively make up the deficiency of existing evaluation methods.

Keywords Water diversion project · Set pair analysis · Algae · Shellfish · Risk evaluation · Weight

Introduction

In recent years, along with rapid population growth and economic development, uneven distribution of water resources and imbalance in regional water demand have intensified, which give birth to inter-basin water diversion projects (Chen et al. 2021; Ren et al. 2021; Cai et al. 2021). The water diversion projects have not only changed the water resources situation in the receiving area, but also interrupted its ecological balance (Peng et al. 2021) by causing fast invasion of algae and shellfish, biofouling, water quality deterioration, and other phenomena. Since the middle route of South-to-North Water Diversion Project was put into operation, on the one hand, there has been rapid algae proliferation in a specific period due to changes in nutrient salt and hydrodynamic conditions as well as water pollution accidents; and on the other hand, freshwater mussels have appeared in the main canal of the middle route and showed an increasing momentum along the route, which has broken the ecosystem structure of the middle-route canals and affected waterworks along the route.

In the past decade, the outbreak frequency of algal blooms in Arabian Gulf has elevated remarkably, which has affected drinking water sources and tightened residents' shortage of domestic water (Maryam et al. 2014). The outbreak of green algae has become an ecological problem in the southern Yellow Sea (Li et al. 2021). Accurate prevention and control of abnormal algae and shellfish proliferation is an urgent task at present, and the premise of accurate prevention and control lies in determining

Responsible Editor: Lotfi Aleya

✉ Youming Li
616556786@qq.com

1 School of Water Resources and Electric Power, Hebei University of Engineering, Handan 056038, Hebei Province, China

2 Hebei Key Laboratory of Smart Water Conservancy, Hebei University of Engineering, Handan 056038, Hebei Province, China

3 Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100038, China

the risk level of abnormal proliferation in a quickly and accurate manner. At present, many scholars both at home and abroad have carried out studies on the middle route's risk assessment. In the Nanganur region, the water quality index method was used to assess nitrate contamination and associated health in groundwater, indicating that infants are at 1.5 times the risk compared to adults (Adimalla and Hui 2019). Changes in hydrological properties at the source of inter-basin water transfer projects can affect the structure and abundance of zooplankton communities (Kandathil et al. 2020). Combined with multi-objective optimization model and genetic algorithm, a water rights trading scheme is proposed, which shows that the middle line of the South-to-North Water Diversion Project has alleviated the water shortage in Henan Province (Dou et al. 2019). A multi-attribute decision-making method is proposed by combining set pair analysis with interval-valued intuitionist fuzzy, and the results show that this method can obtain the best weights (Kumar and Chen 2020). Toxic dinoflagellates are an invasive species in Europe, and measures to control the toxic dinoflagellates are proposed by combining future climate change scenarios from niche models with future dam construction data (Macêdo et al. 2021). Influenced by seaweed farming near Osaka, Japan, a 3D model was developed to evaluate the water quality of the sewage plant, and it was concluded that the discharge volume of the diversion outlet should be reduced by 28% (Yusuke et al. 2018). Using a spatially referenced regressions on watershed attributes model to study water quality in Weldona, it was found that urban air pollution contributes up to 20% of the total maximum daily nitrate load on the 14th section of the South Platte River (Wetherbee et al. 2022). Harmful algae pose a serious threat to the US state of California, using a system to predict the likelihood of blooms, suggesting that blooms can be reduced by absorbing toxins (Clarissa et al. 2016). The accumulation level of toxic metals in red algae on the coastline of Sudan in the Red Sea was studied by means of cluster analysis, indicating that the overall hazard value is less than 1, which is an acceptable risk level (Ali et al. 2021).

There are still some problems in the above studies: (1) algal and shellfish are not considered together for risk assessment; (2) there is no set of methods to quantitatively de-generalize risk. Therefore, a comprehensive risk assessment method is needed, which is based on a series of quantitative static or dynamic indicators to reflect the comprehensive risk level of algal shellfish and considers the relationship between these indicators. Given the above-mentioned research needs, this paper, taking the middle route of South-to-North Water Diversion Project as the object, established a comprehensive risk evaluation system of algae and shellfish based on comprehensive weighting and four-element connection number by integrating the analytic hierarchy process (AHP) and the weight assignment theory of CRITIC, in a bid to provide information support for the emergency management system of long-distance water diversion projects.

Profile of the target research areas

The water source area of the middle route of South-to-North Water Diversion Project is Danjiangkou Reservoir in Hubei Province, and its main canals span three provinces of Hubei, Henan, and Hebei before flowing to Beijing and Tianjin (Lei et al. 2017). The main canal in the middle route is 1277 km long, involving more than 1750 engineering buildings throughout the line (Long et al. 2016). By July 19, 2021, the middle route of South-to-North Water Diversion Project had supplied water to Henan, Hebei, Beijing, and Tianjin respectively at 13.5 billion m^3, 11.6 billion m^3, 6.8 billion m^3, and 6.5 billion m^3, which totaled 40 billion m^3 in water diversion, 5.9 billion m^3 in ecological water supplement, and 79 million of a cumulative beneficiary population (Hu and Wang 2021; Cheng 2021), as shown in Fig. 1 (Nong et al. 2020).

Comprehensive risk evaluation methodology on algae and shellfish

The comprehensive risk evaluation process of algae and shellfish in the middle route of South-to-North Water Diversion Project includes the following main steps: building a safety risk assessment index system, determining the safety risk grading standards of evaluated objects, calculating the weights of different assessment indexes, constructing a set pair evaluation model, calculating the set pair potential and partial connection number of indexes, and determining the risk grade, as shown in Fig. 2. The evaluation criteria of the 21 indicators are shown in Table A of Supplementary Materials.

Building a safety risk assessment index system

By analyzing components and causes of the risk system, an evaluation system of algae and shellfish in the middle route of South-to-North Water Diversion Project is constructed. This evaluation system encompasses two categories of factors: hazard factors and carriers. The primary indexes: hazard factors include physical, chemical, and biological indicators; carriers include the degree of damage, exposure, and vulnerability of projects. The secondary indexes include 21 factors, as shown in Fig. 3.

Safety grade standards

According to the *National Emergency Plan for Environmental Emergencies* revised in 2015, the comprehensive safety risks of algae and shellfish in the middle route of South-to-North Water Diversion Project is divided into four grades. See Table 1 for detailed classification and connotation.

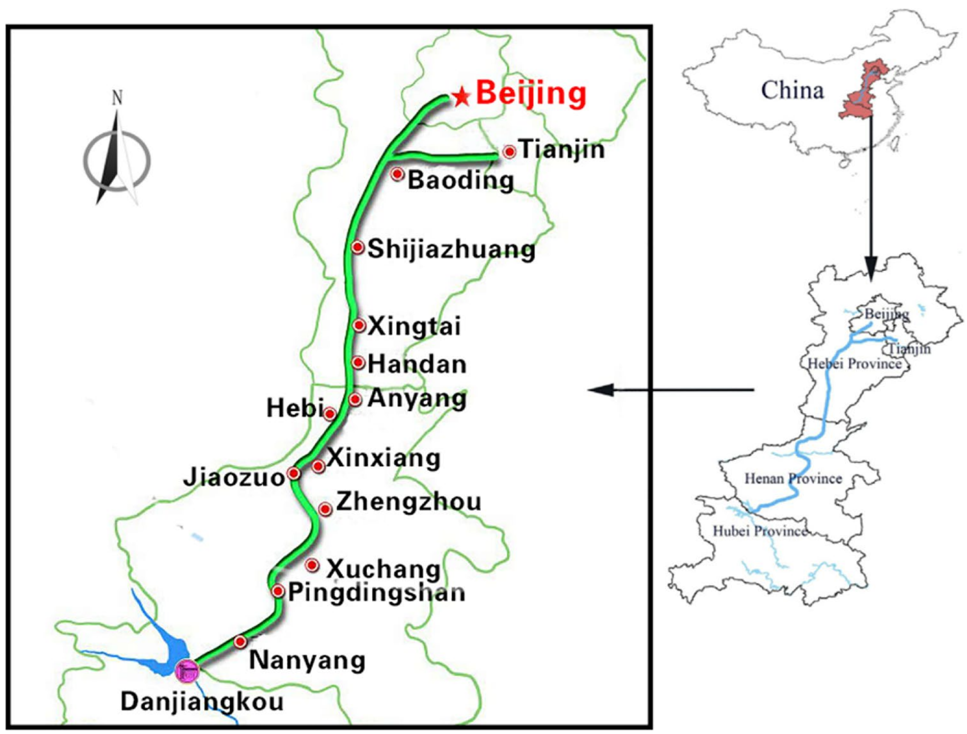

Fig. 1 Sketch map of the middle route of South-to-North Water Diversion Project

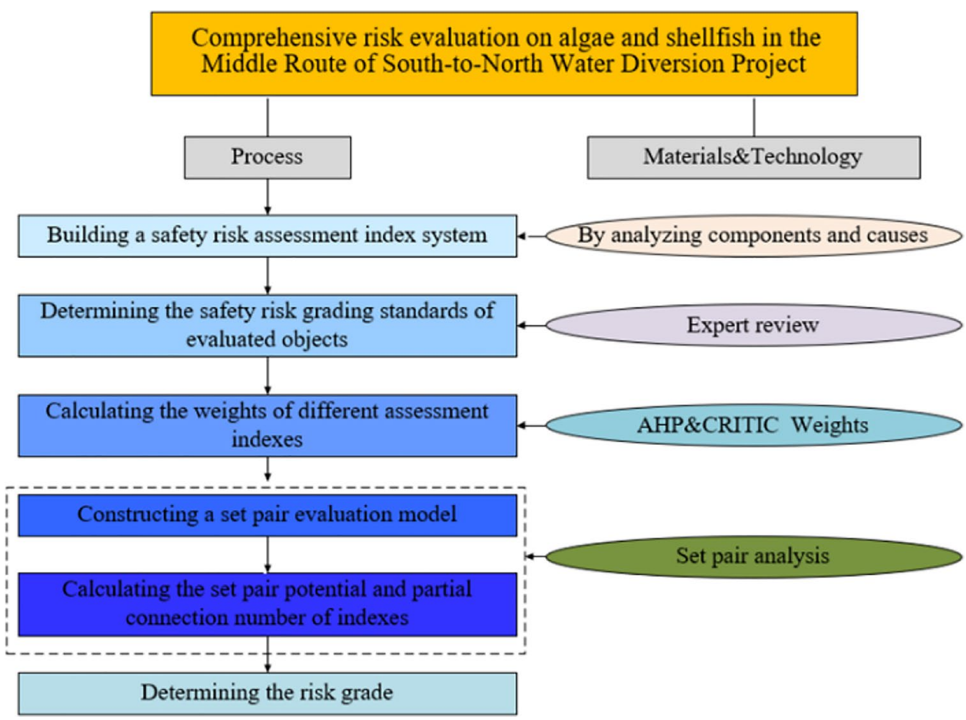

Fig. 2 Diagram of comprehensive risk evaluation on algae and shellfish in the middle route of South-to-North Water Diversion Project

Determining weights of indexes

The subjective weights are determined by experts with their own experience, which are subject to subjective judgment; the objective weights are determined by original data, but they cannot reflect the importance attached by the judges to different factors (Guo 2018). Therefore, the comprehensive weight calculation method is adopted. The subjective weights w_i' are obtained by AHP (Doğan and İÇ 2021). The AHP includes four steps: first, establishing a hierarchical

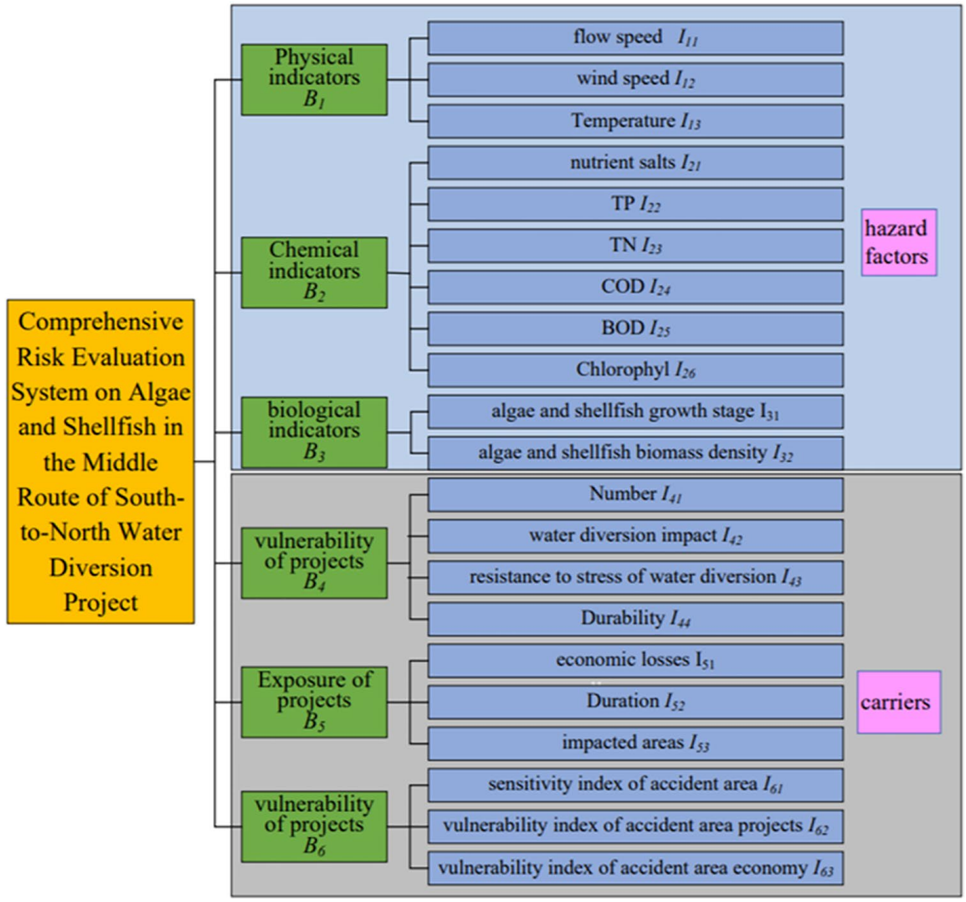

Fig. 3 Comprehensive risk evaluation system on algae and shellfish in the middle route of South-to-North Water Diversion Project

Table 1 Safety risk assessment grading

Safety grade	I	II	III	IV
Safety situation	Highly safe	Relatively safe	Safe	Unsafe
Symbols	1	*i*	*j*	*k*

structure model; second, constructing a judgment matrix; third, examining single sequencing and consistency; fourth, obtaining the weight. See reference (Doğan and İÇ 2021) for the detailed calculation process.

The objective weights w_i^{ε} are obtained by the weight method of CRITIC (criteria importance through intercriteria) (Ji et al. 2021). The CRITIC includes four steps: first, standardizing evaluation indexes; second, calculating correlated coefficients of the indexes; third, calculating the variability and conflict of the indexes; fourth, calculating the weight. See reference (Ji et al. 2021) for the detailed calculation process. The weights obtained by AHP and CRITIC are combined into the comprehensive weight .

$$w_i = \lambda w_i' + (1 - \lambda) w_i^{\varepsilon} \tag{1}$$

where λ is the preference coefficient, and usually $\lambda = 0.5$; w_i is the comprehensive weight of the i-th index.

Constructing the set pair evaluation model

There are four grades for the comprehensive risk evaluation of algae and shellfish in the middle route of South-to-North Water Diversion Project. Therefore, the quaternion connection function is adopted for set pair analysis.

The first step is to construct an index evaluation matrix. N experts are asked to determine the risk grade of each index, among whom n experts think that the risk grade of the index falls in grade i, then the level I evaluation result of the index for grade I is $u_{ij} = \frac{n}{N}$, which constitutes the index evaluation matrix C, whose expression is as follows:

$$C = \begin{bmatrix} u_{11} & u_{12} & u_{13} & u_{14} \\ u_{21} & u_{22} & u_{23} & u_{24} \\ \vdots & \vdots & \vdots & \vdots \\ u_{n1} & u_{n2} & u_{n3} & u_{n4} \end{bmatrix}$$

The second step is to establish the quaternion connection function. The safety grading standard matrix $A = [1, i, j, k]$ is obtained in the "Safety grade standards" section. The comprehensive weight matrix $B = [\, w_1, w_2, \cdots, w_n]$ of each index is obtained in the "Determining weights of indexes" section. And the index evaluation matrix C is obtained in this section. The quaternion connection function is expressed as follows:

$$\mu = \left[w_1, w_2, \cdots, w_n\right]\left[C = \begin{matrix} u_{11} & u_{12} & u_{13} & u_{14} \\ u_{21} & u_{22} & u_{23} & u_{24} \\ \vdots & \vdots & \vdots & \vdots \\ u_{n1} & u_{n2} & u_{n3} & u_{n4} \end{matrix}\right]\begin{bmatrix} 1 \\ i \\ j \\ k \end{bmatrix} = \sum_{r=1}^{n} w_r u_{r1} + \sum_{r=1}^{n} w_r u_{r2} i + \sum_{r=1}^{n} w_r u_{r3} j + \sum_{r=1}^{n} w_r u_{r4} k \tag{2}$$

For convenience of follow-up reference, the above expression is usually represented with:

$$\mu = a + bi + cj + dk \tag{3}$$

Calculating set pair potential and partial connection number

The changing trends of set pairs is expressed by a/d in formula (3); if $a/d > 1$, it is the same potential, which indicates the unified momentum between risk and ideal state, a low-risk state; if $a/d = 1$, it is the average potential, which means that the risk has an equal status with the ideal state, a medium-risk state; and if $a/d < 1$, it is the opposite potential, which demonstrates that the risk is in the opposite momentum to the ideal state, a high-risk state.

The same potential in the table below means that the risk of algae in the South-to-North Water Diversion Project will develop in a good direction; the balance of potential means that the risk of algae in the middle of the South-to-North Water Diversion will remain unchanged; the opposite trend means that the risk of algae in the middle of the South-to-North Water Diversion will develop in a bad direction. For the calculation, the partial connection coefficient of the upper level will affect the calculation of the partial connection coefficient of the next level.

Partial number is a quantitative analysis of deviation trend, which can effectively reflect the dynamic changes of indexes. The calculation formulas of partial connection number of each order are as follows (Hong et al. 2014; Zheng and Han 2018):

First-order partial connection number:

$$\partial u = \partial a + i\partial b + j\partial c \tag{4}$$

where $\partial a = \frac{a}{a+b}, \partial b = \frac{b}{b+c}, \partial c = \frac{c}{c+d}$.

Second-order partial connection number:

$$\partial^2 \mu = \partial(\partial u) = \partial^2 a + i\partial^2 b \tag{5}$$

where $\partial^2 a = \frac{\partial a}{\partial a+\partial b}, \partial^2 b = \frac{\partial b}{\partial b+\partial c}$.

Third-order partial connection number:

$$\partial^3 \mu = \partial^2(\partial \mu) = \partial^3 a \tag{6}$$

where $\partial^3 a = \frac{\partial^2 a}{\partial^2 a+\partial^2 b}$.

Determining the safety risk grade

The weighted average connection degrees of each safety grade are obtained through formula (3) and compared, before determining the final safety grade (Qiu and Yang 2020).

For example, grade S:

$$\mathrm{S} = \max(a, b, c, d) = c \tag{7}$$

where c represents grade III, denoting a safe state.

Case study

Determining index weight

The target research area of this paper is the Henan section of the middle route of South-to-North Water Diversion Project, and the data are retrieved from April 2016 to April 2019. According to the calculation method of comprehensive weighting, the weights obtained by AHP and CRITIC are combined into comprehensive weights, as shown in Fig. 4.

Constructing set-pair connection function

A questionnaire survey was conducted among 30 experts, who, on the basis of their experience, knowledge reserve, and personal values, evaluated the safety grade of each index in combination with the features of the middle route of South-to-North Water Diversion Project, thus forming the index evaluation matrix for algae and shellfish in the middle route, as shown in Table 2 for details. And the quaternion connection function is established according to formula (2), as shown in Table 3.

As shown in Table 3, the quaternion connection function of algae and shellfish in the middle route of South-to-North Water Diversion Project is $0.28 + 0.25i + 0.26j + 0.21k$, and its set pair potential is 1.75, which shows the same potential

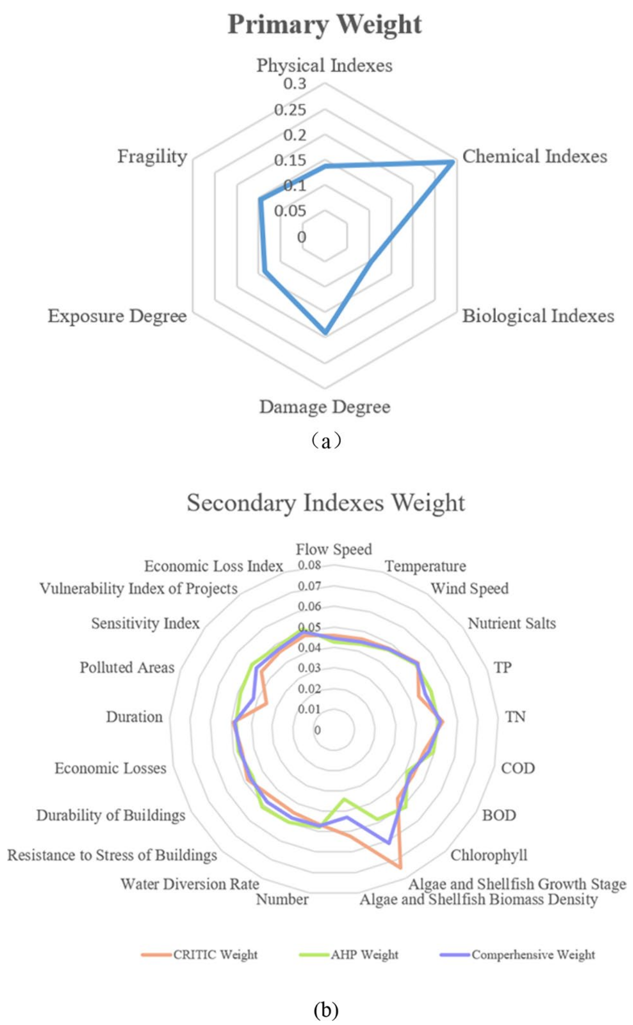

Fig. 4 Weights of algae and shellfish in the middle route of South-to-North Water Diversion Project

between the ideal state and actual risk, registering relatively small risks. Among primary indexes, physical and biological ones feature opposite potential; chemical ones feature average potential; and damage degree, exposure degree, and vulnerability feature same potential. Among secondary indexes, temperature, nutrient salts, chlorophyll, growth stage of algae and shellfish, number of projects, and polluted areas feature opposite potential; economic loss index features average potential; and the rest indexes all feature same potential.

As shown in Fig. 5, the ratio of different sets of first-order partial connection number and second-order partial connection number to the situation is calculated. In the partial connection number of the first-level indicators, the opposite potential accounts for 33%; the same trend accounted for 67%; and average accounts for 0%. In the partial connection number of secondary indicators, the opposite potential accounts for 28%; the same trend accounted for 67%; and the proportion of average is 5%. The proportion of partial connections of primary indicators is different from that of secondary indicators, because primary indicators are the result of comprehensive consideration of secondary indicators, and primary indicators are closer to the overall trend of partial connections.

Calculating the partial connection number and set pair potential of each order

Risk potential are obtained by analyzing the ratio of a/d according to formulas (4)–(6). See Table 4 for details of partial connection number and set pair potential of each order.

(1) As shown in Table 4, the first-order partial connection number for comprehensive risk assessment of algae and shellfish in the middle route of South-to-North Water Diversion Project is $0.53 + 0.49i + 0.55j$, and the set pair potential is 0.96. The ideal state and actual risks feature opposite potential; namely, algae and shellfish in the middle route show a first-order risk rising momentum. Among primary indexes, the safety potential of damage degree features opposite potential; biological indexes and exposure degree feature average potential; and other indexes feature same potential.

(2) As shown in Table 4, the second-order partial connection number for comprehensive risk assessment of algae and shellfish in the middle route of South-to-North Water Diversion Project is $0.52 + 0.47i$, and the set pair potential is 1.11. The ideal state and actual risks feature same potential; namely, algae and shellfish in the middle route show a second-order risk falling momentum. Among primary indexes, the safety potential of biological indexes, damage degree, and fragility feature opposite potential; and other indexes feature same potential.

(3) As shown in Table 4, the third-order partial connection number for comprehensive risk assessment of algae and shellfish in the middle route of South-to-North Water Diversion Project is 0.52. The ideal state and actual risks feature same potential; namely, algae and shellfish in the middle route show a third-order risk falling momentum. Among primary indexes, the safety potential of biological indexes, damage degree, and fragility feature opposite potential; and other indexes feature same potential.

As shown in Fig. 6, in the situation of the first-order partial connection number in the middle route of South-to-North Water Transfer Project, the reverse potential accounts for 50%; the same trend accounted for 33%; and the balance of power is 17%. In the situation of the second-order partial connection number of the South-to-North Water Transfer

Table 2 Index evaluation matrix for algae and shellfish in the middle route of South-to-North Water Diversion Project

Evaluation indexes	Highly safe	Relatively safe	Safe	Unsafe
Flow speed	0.3	0.1	0.3	0.3
Temperature	0.15	0.15	0.35	0.35
Wind speed	0.3	0.35	0.2	0.15
Nutrient salts	0.25	0.25	0.2	0.3
TP	0.3	0.2	0.3	0.2
TN	0.25	0.2	0.4	0.15
COD	0.3	0.3	0.2	0.2
BOD	0.4	0.2	0.3	0.1
Chlorophyll	0.2	0.2	0.3	0.3
Algae and shellfish biomass density	0.1	0.3	0.2	0.4
Algae and shellfish growth stage	0.4	0.2	0.3	0.1
Number	0.3	0.4	0.25	0.05
Water diversion rate	0.35	0.35	0.15	0.15
Resistance to stress of buildings	0.3	0.4	0.2	0.1
Durability of buildings	0.2	0.5	0.2	0.1
Economic losses	0.25	0.3	0.25	0.2
Duration	0.4	0.2	0.3	0.1
Polluted areas	0.15	0.15	0.3	0.4
Sensitivity index	0.5	0.2	0.1	0.2
Vulnerability index of projects	0.4	0.1	0.3	0.2
Economic loss index	0.2	0.2	0.4	0.2

Project, the reverse potential accounts for 50%, and the same potential also accounts for 50%. The third-order proportion is the same as the second-order proportion. Compared with the second-order partial connection number, the equilibrium of the first-order partial connection number disappears in the second-order partial connection situation, which is due to the chemical index showing counter potential in the second-order partial connection situation and showing equilibrium in the first-order partial connection situation. The proportion of the second-order partial connection number situation and the third-order partial connection number situation has no obvious change, because there is no change in the second-order partial connection number situation and the third-order partial connection number situation. The deviation trend of each stage is progressive and calculated in turn.

Determining safety grade of algae and shellfish in middle route of South-to-North Water Diversion Project

The overall risk correlation coefficient obtained from Table 4 is [0.28, 0.25i, 0.26j, 0.2k]. The above results show that for the Henan section of the middle route of South-to-North Water Diversion Project, the risk correlation coefficient of grade I (highly safe) is 0.28, grade II (relatively safe) is 0.25, grade III (safe) is 0.26, and grade IV (unsafe) is 0.2. According to formula (7), by comparing the risk connection coefficients of different grades, the risk connection coefficient of grade I is the largest, so the overall safety grade of Henan section of the middle route of South-to-North Water Diversion Project is grade I, a highly safe state.

Discussion

(1) Among the evaluation indexes of the comprehensive risk assessment model of algae and shellfish, the growth stage, nutrient salts, and TN occupy the largest weights, which prove to be important indexes affecting the overall risk. Therefore, it is necessary to focus on the growth stage and chemical indexes of algae and shellfish.

(2) At present, the comprehensive risk of algae and shellfish in the Henan section of the middle route of South-to-North Water Diversion Project is in a highly safe state and is expected to present a safe momentum in the future. However, in the first-order overall potentials, both physical and biological indexes show opposite potential; namely, the physical factors in the Henan section are suitable for the growth of algae and shellfish. Therefore, it is necessary to strengthen the monitoring of physical indexes and pay close attention to the growth of algae and shellfish.

Table 3 Quaternion connection functions for indexes at all grades in the middle route of South-to-North Water Diversion Project

Primary indexes	Secondary indexes	Quaternion connection function	Potential
Physical indexes	Flow speed	$0.3 + 0.1i + 0.3j + 0.3k$	Same
	Temperature	$0.15 + 0.15i + 0.35j + 0.35k$	Opposite
	Wind speed	$0.3 + 0.35i + 0.2j + 0.15k$	Same
Physical indexes totality		$0.25 + 0.20i + 0.28j + 0.27k$	Opposite
Chemical indexes	Nutrient salts	$0.25 + 0.25i + 0.2j + 0.3k$	Opposite
	TP	$0.3 + 0.2i + 0.3j + 0.2k$	Same
	TN	$0.25 + 0.2i + 0.4j + 0.15k$	Same
	COD	$0.3 + 0.3i + 0.2j + 0.2k$	Same
	BOD	$0.4 + 0.2i + 0.3j + 0.1k$	Same
	Chlorophyll	$0.2 + 0.2i + 0.3j + 0.3k$	Opposite
Chemical indexes totality		$0.56 + 14i + 0.12j + 0.16k$	Same
Biological indexes	Algae and shellfish stage	$0.1 + 0.3i + 0.2j + 0.4k$	Opposite
	Algae and shellfish density	$0.4 + 0.2i + 0.3j + 0.1k$	Same
Biological indexes totality		$0.22 + 0.26i + 0.24j + 0.28k$	Opposite
Damage degree	Number	$0.3 + 0.4i + 0.25j + 0.5k$	Opposite
	Water diversion rate	$0.35 + 0.35i + 0.15j + 0.15k$	Same
	Resistance to pressure of buildings	$0.3 + 0.4i + 0.2j + 0.1k$	Same
	Durability of buildings	$0.2 + 0.5i + 0.2j + 0.1k$	Same
Damage degree totality		$0.29 + 0.41i + 0.19j + 0.11k$	Same
Exposure degree	Economic losses	$0.25 + 0.3i + 0.25j + 0.2k$	Same
	Duration	$0.4 + 0.2i + 0.3j + 0.1k$	Same
	Polluted areas	$0.15 + 0.15i + 0.3j + 0.4k$	Opposite
Exposure degree totality		$0.27 + 0.22i + 0.28j + 0.23k$	Same
Fragility	Sensitivity index	$0.5 + 0.2i + 0.1j + 0.2k$	Same
	Vulnerability index of projects	$0.4 + 0.1i + 0.3j + 0.2k$	Same
	Economic loss index	$0.2 + 0.2i + 0.4j + 0.2k$	Average
Fragility totality		$0.23 + 0.16i + 0.27j + 0.2k$	Same
Totality		$0.28 + 0.25i + 0.26j + 0.21k$	Same

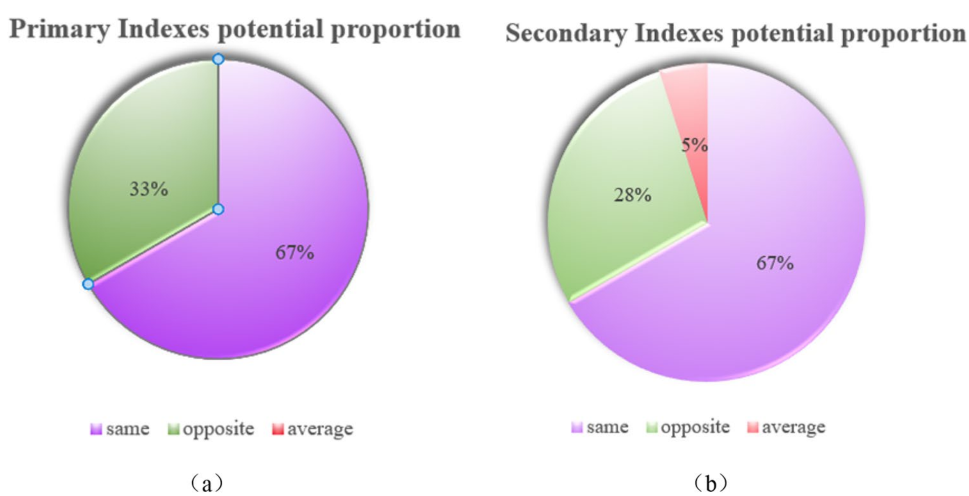

Fig. 5 Risk situation proportion chart of the middle route of South-to-North Water Transfer Project

(3) When comparing and dividing each order partial connection coefficient, the proportion of each situation of the second-order partial connection coefficient is compared with the situation of the first-order partial connection coefficient, and the same potential part of the first-order partial connection coefficient disappears, this is because the chemical index. The situation has changed from the opposite to the same situation; the

Table 4 Partial connection number and set pair potential of each-order indexes for the middle route of South-to-North Water Diversion Project

	First-order partial connection number	Set pair potential	Second-order connection number	Set pair potential	Third-order partial connection number	Set pair potential
Physical indexes	$0.56 + 0.42i + 0.51j$	Same	$0.57 + 0.45i$	Same	0.56	Same
Chemical indexes	$0.80 + 054i + 0.43j$	Same	$0.60 + 0.57i$	Same	0.52	Same
Biological indexes	$0.46 + 0.52i + 0.46j$	Average	$0.47 + 0.53i$	Opposite	0.47	Opposite
Damage degree	$0.41 + 0.68i + 0.63j$	Opposite	$0.38 + 0.52i$	Opposite	0.42	Opposite
Exposure degree	$0.55 + 0.44i + 0.55j$	Opposite	$0.56 + 0.44i$	Same	0.56	Same
Fragility	$0.59 + 0.37i + 0.66j$	Same	$0.61 + 0.36i$	Opposite	0.63	Opposite
Totality	$0.53 + 0.49i + 0.55j$	Opposite	$0.52 + 0.47i$	Same	0.52	Same

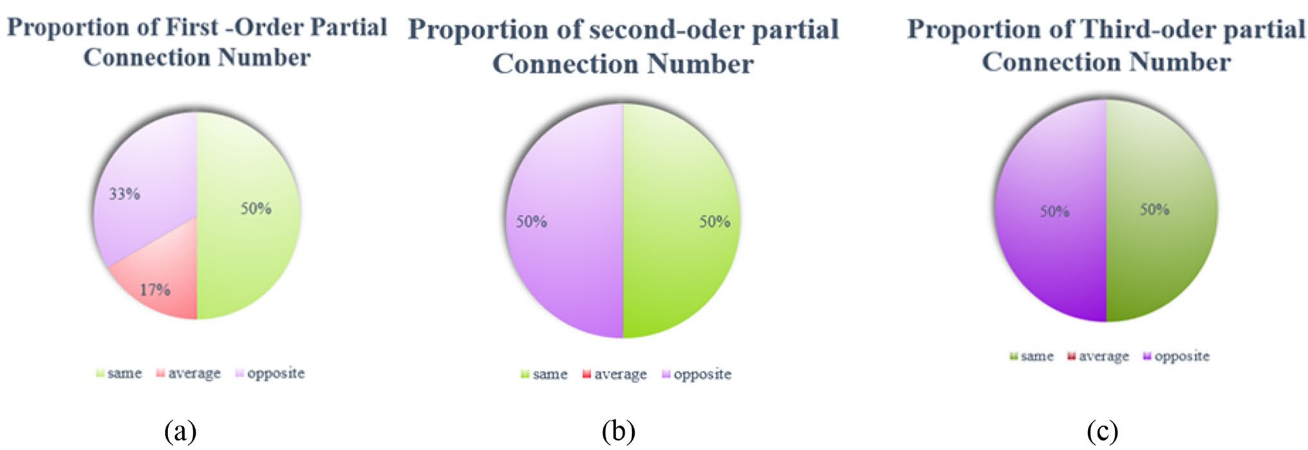

Fig. 6 Proportion of each order situation in the middle route of South-to-North Water Transfer Project

proportion of each situation of the third-order partial connection coefficient is the same as that of the first-order partial connection coefficient, this is because the situation of each indicator has not changed, and it also shows that the line algae in the middle of the South-to-North Water Diversion Project is the same. Shellfish risk stabilized.

Conclusions

(1) By combining the growth properties of algae and shellfish in the middle route of South-to-North Water Diversion Project with set pair analysis, it is concluded that the safety risk grade of the middle-route algae and shellfish is grade I, a highly safe state.

(2) The comprehensive risk assessment system of algae and shellfish in the middle route of South-to-North Water Diversion Project was established, and the comprehensive weights are obtained by combining AHP and CRITIC weights. The comprehensive risk evaluation model of algae and shellfish in the middle route of South-to-North Water Diversion Project was established to grasp the dynamic risk changes of each index by calculating the partial connection numbers of each order: the overall first-order partial connection numbers feature opposite potential, with risks on the rise; the second-order and third-order partial connection numbers feature same potential, with risks in decline.

(3) There are both same and opposite potentials in the quaternion connection numbers and partial connection numbers of each order, which comprehensively shows the dynamism of algae and shellfish risk in the Henan section of the middle route of South-to-North Water Diversion Project.

(4) Among the indicators of algal and shellfish risk assessment in the whole South-to-North Water Diversion Project, the factors that have the greatest impact on the overall risk are the growth stage, nutrient salt, and TN of algae and shellfish.

(5) When analyzing the partial connection coefficients of each order, it is found that the proportion of the first-order partial connection coefficient is compared with that of the second-order partial connection coefficient. This is because the same potential of the first-order partial connection coefficient disappears; the proportion of the third-order partial connection coefficient is the same as that of the second-order partial connection coefficient.
(6) The risk assessment of algae and shellfish in the middle line of the South-to-North Water Diversion is a quantitative evaluation method, and it is also a dynamic evaluation method. In the future, it is hoped that a quantitative method for evaluating the comprehensive risk of algal shellfish can be found.

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Declarations

Ethics approval This article abides by academic norms, and there is absolutely no academic fraud.

Consent to participate All authors are actively involved in the paper and agree to the specifications of your journal.

Consent for publication All authors agree to submit to your journal, one publication, never multiple submissions for one manuscript.

Conflict of interest The authors declare no competing interests.

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