Environmental Risk Assessment of a Water Diversion Project for Improving the Water Quality of Chaohu Lake: A Case Study

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Abstract. New method for assessing the environmental risk of water diversion projects is proposed. Fault tree analysis was used to identify risk sources. The project route was divided into four regions: water source region, conveyance region, receiving water region, and drainage region. According to the different characteristics of the four regions, a risk evaluation index system and a multi-layer fuzzy comprehensive evaluation model were established. The results indicated that the environmental risk grade in the water source region was low and those of the other regions were medium-low. This work contributes to the environmental feasibility analysis of water diversion projects.

1. Introduction

Chaohu Lake is one of the five largest freshwater lakes in China and plays a huge role in water storage, flood control, water supply, agricultural irrigation, aquatic products, travel, and etc.[1]With the economy development and population increase, the gradual accumulation of pollution load has exceeded the carrying capacity of the lake, leading to serious eutrophication and loss of ecological function. Water diversion project has been considered as an important and helpful measure to improve water quality in the area. To improve the water quality of Chaohu Lake, a water diversion project was proposed by The Water Resources Department of Anhui Province. However, the water diversion project is complicated and can be influenced by many uncertain factors. So its environmental must be assessed before implementation.

The importance of environmental impact assessment of hydraulic engineerings has been widely recognized. A number of studies on water diversion risk assessment have been performed. Chang et al.[2]presented a comprehensive evaluation index system as a basis for evaluating the impact of inter-basin water diversion on ecological environment. The comprehensive evaluation index system included a target layer, a rule layer, and an index layer. Dou et al.[3]stated that the middle route of the South-to-North Water Transfer Project may produce adverse impacts on the ecological environment of Hanjiang. Yuan[4]established the comprehensive evaluation index system and a multilevel linear weighting and fuzzy mathematical comprehensive evaluation model to assess the environmental impacts of the Three Gorges Project. Xu et al.[5]analysed the “Two Rivers and Two Stations” project for Chaohu, discussed projects that may produce impacts on the social, economic, and ecological environment, and defined an index system. They used field investigation, analysis by analogy, expert

consultation, and an analytic hierarchy to determine the main impact factors, which they conceptualized as a factor set to carry out a fuzzy comprehensive evaluation. Wang et al.[6]established an evaluation index system and used multi-level fuzzy comprehensive evaluation methods to analyse the social impacts of a water transfer project in Heihe River basin. Jin et al.[7]proposed a risk assessment system for water transfer projects that was structured according to the characteristics of water transfer project accidents. Chen et al.[8]analysed the risk factors of long-distance water transfer project system, which related to hydrology, buildings, economy, policy, the environment, and society. Extremum statistical methods, probability risk analysis methods, gray stochastic risk analysis, maximum entropy risk analysis, and many other methods have also been used[9]-[12].

Most previous studies involving environmental risk assessment of water diversion projects have focused on water quality assessment or safety evaluation of hydraulic structures. Only a small body of published research exists on comprehensive evaluation of environmental risk for a water diversion project. Therefore, in this paper, an environmental risk assessment model has been constructed and applied to the Chaohu water diversion project, which can provide a reference for feasibility analysis of water diversion projects.

2. Materials and Methods

2.1. Study Area

The route of the Chaohu Lake ecological water diversion project is shown in Figure 1.

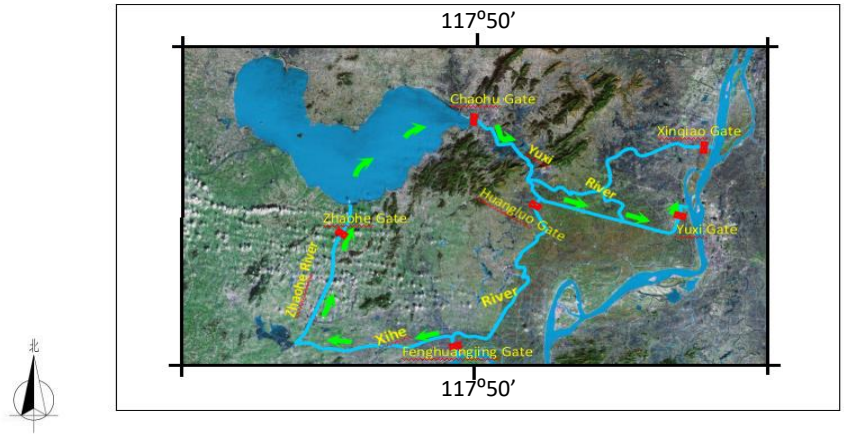

Figure 1. Route of the water diversion project.

According to the natural water diversion process, the route was divided into four regions: the water source region, the conveyance region, the receiving water region, and the drainage region:

①Water source region: the reach of the Yangtze River from a point 3km upstream of the FenghuangjingGate to a point 2km downstream;

②Conveyance region: the Xihe and Zhaohe Rivers;

③Receiving water region: East Chaohu Lake.

④Drainage region: the Yuxi River and the reach of the Yangtze River from 3km upstream of the YuxiGate to 7km downstream.

2.2. Environmental Risk Assessment Method

To control the negative influences and environmental risks which may occur during ecological water transfer, an environment risk assessment was undertaken. The procedure is shown in Figure 2.

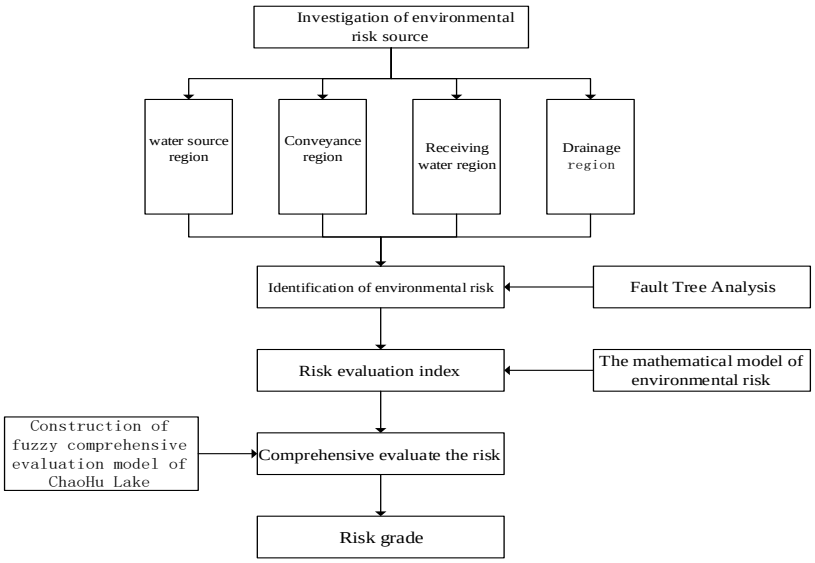

Figure 2. The flowchart of environment risk assessment

2.3. Source Identification of Environmental Risk

Figure 2 showsthat the first step is identifying the sources of risk. Here, fault tree analysis as an environmental risk identification method has been applied to the Chaohu Lake ecological water diversion project. This approach has been discussed in detail in the literature[13].

2.4. Construction of the Risk Evaluation Index System

According to the source identification of environmental risk and the characteristics of the four regions, a risk evaluation index system was introduced and is shown in Table 1. This system includes 50 indices in five layers: the object layer, the sub-object layer, the criterion layer, the sub-criterion layer, and the index layer.

2.5. Construction of the Fuzzy Comprehensive Evaluation Model

The fuzzy comprehensive evaluation method was used to evaluate the risk of the Chaohu Lake ecological water diversion project. This method was used because of its advantages in solving problems that are vague and hard to quantify. The basic steps are as follows[15]:

(1) According to environmental risk characteristics, the evaluation set is divided into five levels: $V=\{V_1,V_2,V_3,V_4,V_5\}=\{$low,medium–low, medium, medium–high, high$\}$.

(2) Determine the classification standard that determines the membership degree of each index. Membership degrees lie between 0 and 1.

(3) Determine the weight matrix. The weight of an index depends on its importance.

(4) Determine a fuzzy evaluation model and obtain results. The calculation formula is:

$$D_i=w_{ij}R_{ij}$$

Where D_i is the evaluation result for index i, w_{ij} is the weight of index i, and R_{ij} is the membership degree of index i. Based on the formula, the risk value can be calculated layerbylayer. The last result is the overall evaluation result provided by the model.

Assign an environmental risk grade according to the following classification: low risk is between 0 and 1, low-medium risk is between 1 and 2, medium risk is between 2 and 3, medium-high risk is between 3 and 4, and high risk is between 4 and 5.

3. Results and Discussion

The environmental risk assessment method was used in the current study, with the results shown in Table 2. It is apparent that the risk grade of the water source region is low, whereas those of the other regions are medium-low.

Table 1. Risk evaluation index system of the Chaohu Lake ecological water diversion project

Object layer	Sub-object layer	Criterion layer	Sub-criterion layer	Index layer
Environmental risk assessment of water diversion project	Risk evaluation of water source region	Water quantity risk	Reliability of water quantity	Available amount of water in the Yangtze
			Reliability of the hydraulic facilities	Reliability of water transfer facilities
				Operating skills and level of management
		Water quality risk	Upstream water quality	Water quality assessment
				Comparison with receiving waterquality
			Influence of the drainage outlet	Discharge capacity
				Distance from water inlet
			Shipping pollution index	Shipping sewage volume
				Petroleum emissions
				Crew operating level
				Risks of oil spill
		Ecological risk	Oncomelania diffusion risk	Appearance rate of living oncomelanias contained in box
				Average density of living oncomelanias
				Infection rates of oncomelanias
	Risk evaluation of conveyance region	Water quality risk	Water quality in the water transport channel	Exceed the water quality standard about Xihe
				Exceed the water quality standard about Zhaohe
				Water quality compared to the conveyance region
			Analysis of the drainage outlet	Scope of normal discharge
				Scope of accidental discharge
			Vessel pollution index	Oily wastewater emissions
				Petroleum emissions
				Operating status of environmental protection facilities
			Influence of aquaticbreeding	Proportional area of aquatic breeding
		Ecological risk	Possibility of oncomelania diffusion by floating	Number of oncomelanias outside the gate
				Number of oncomelanias inside the gate
			Possibility of oncomelania diffusion with vessels	Proportion of vessels carrying oncomelanias
	Risk evaluation of receiving water region	Water quality risk	Water quality of the area	The condition of exceed the water quality standard
				Risks regarding the distribution of water quality differences

		Influence of the river on the lake	Area of influence
			Impact on intake (concentration increment)
		Eutrophication of water bodies	Ratio of nitrogen to phosphorus
			Change in water temperature
		Vessel pollution index	Oily wastewater emissions
			Petroleum emissions
			Operating status of environmental protection facilities
	Ecological risk	Possibility of oncomelanias breeding and multiplying in Chaohu	Survival rates of oncomelanias in the wild
			Development status of the offspring of oncomelanias
	Other Risks	Flood risk	Flood risk
			Drainage risk
			Risk of sediment deposition
		Risks of water resource utilization	Risk of irrigation water
			Shipping risk
Risk evaluation of drainage region	Risk of the Yuxi River	Influence on water quality in theYuxi River	Water quality compared to water source region
			Water quality compared to conveyance region
		Impact on intake	Increment of COD concentration
	Risk of the Yangtze River	Water quality of the Yangtze in the outlet section	Water quality compared to water source region
			Water quality compared to conveyance region
		Influence on Yangtze water quality	Length of the influence
			Width of the influence
		Impact on intake	Concentration increment

Table 2. Comprehensive evaluation results for each region.

Region	Water source region	Conveyance region	Receiving water region	Drainage region
Evaluation results	0.192	0.352	0.384	0.345
Risk standard values	0.975	1.76	1.92	1.72
Risk grade	low	medium–low	medium–low	medium–low

4. Conclusions

In this paper, a new method for assessing the environmental risk of water diversion projectshas been proposed. Fault tree analysis was used to identify risk sources during water diversion. The project route was divided into four regions: the water source region, the conveyance region, the receiving water region, and the drainage region.To reflect the different characteristics of the four regions, a risk evaluation index system was introduced, including 50 indices in five layers: the object layer, the sub-object layer, the criterion layer, the sub-criterion layer, and the index layer. A fuzzy comprehensive evaluation model was used to evaluate the risk of the Chaohu Lake ecological water

diversion project. Using this method, project risk wassuccessfully assessed. The results indicated that the environmental risk forthe water source region was in the low range and for the other regions were in the medium-low range. This work contributes to feasibility analysis of water diversion projects.

5. References

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