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.](image)

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:

1. Water source region: the reach of the Yangtze River from a point 3km upstream of the FenghuangjingGate to a point 2km downstream;
2. Conveyance region: the Xihe and Zhaohe Rivers;
3. Receiving water region: East Chaohu Lake;
4. Drainage 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.
Investigation of environmental risk source

water source region → Conveyance region → Receiving water region → Drainage region

Identification of environmental risk → Fault Tree Analysis

Risk evaluation index → The mathematical model of environmental risk

Construction of fuzzy comprehensive evaluation model of Chaohu Lake

Comprehensive evaluate the risk → Risk grade

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={V₁,V₂,V₃,V₄,V₅}={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 |
|--------------|------------------|-----------------|---------------------|-------------|
|              |                  | Water quantity risk | Available amount of water in the Yangtze |  |
|              |                  | Water quantity risk | Reliability of the hydraulic facilities |  |
|              |                  | Water quantity risk | Operating skills and level of management |  |
| Risk evaluation of water source region | Upstream water quality | Water quality assessment | Discharge capacity |  |
|              |                  | Upstream water quality | Distance from water inlet |  |
|              |                  | Upstream water quality | Shipping sewage volume |  |
|              |                  | Upstream water quality | Petroleum emissions |  |
|              |                  | Upstream water quality | Crew operating level |  |
|              |                  | Upstream water quality | Risks of oil spill |  |
|              |                  | Ecological risk | Oncomelania diffusion risk |  |
|              |                  | Ecological risk | Average density of living oncomelania |  |
|              |                  | Ecological risk | Infection rates of oncomelania |  |
| Environmental risk assessment of water diversion project | Water quality in the water transport channel | Exceed the water quality standard about Xihe |  |
|              |                  | Water quality in the water transport channel | Exceed the water quality standard about Zhaohe |  |
|              |                  | Water quality in the water transport channel | Water quality compared to the conveyance region |  |
| Risk evaluation of conveyance region | Analysis of the drainage outlet | Scope of normal discharge |  |
|              |                  | Analysis of the drainage outlet | Scope of accidental discharge |  |
|              |                  | Analysis of the drainage outlet | Oily wastewater emissions |  |
|              |                  | Analysis of the drainage outlet | Petroleum emissions |  |
|              |                  | Analysis of the drainage outlet | Operating status of environmental protection facilities |  |
|              |                  | Vessel pollution index | Proportional area of aquatic breeding |  |
|              |                  | Vessel pollution index | Number of oncomelanias outside the gate |  |
|              |                  | Vessel pollution index | Number of oncomelanias inside the gate |  |
| Ecological risk | Possibility of oncomelania diffusion by floating | Possibility of oncomelania diffusion with vessels | Proportion of vessels carrying oncomelania |  |
|              |                  | Possibility of oncomelania diffusion by floating | The condition of exceed the water quality standard |  |
|              |                  | Possibility of oncomelania diffusion by floating | Risks regarding the distribution of water quality differences |  |
Influence of the river on the lake

Eutrophication of water bodies

Vessel pollution index

Ecological risk

Possibility of oncomelanias breeding and multiplying in Chaohu

Other Risks

Risk of the Yuxi River

Risk of the Yangtze River

Risk evaluation of drainage 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 |

Table 2. Comprehensive evaluation results for each region.

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 was successfully assessed. The results indicated that the environmental risk for the 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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