Research on the Interaction of Environmental Factors in the Three Gorges Reservoir Area Based on the Two-layer Network System Dynamics Model

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Abstract. This paper takes the ecological security of the Chongqing Three Gorges Reservoir area as the research object, establishes five subsystems of policy, population, water environment, economy, and biology, and uses the analytic network process to calculate the impact weights of different indicators in each layer of the system. The results show that the weight of the water environment indicator layer is the largest, and other indicators have varying degrees of impact on ecological security. On this basis, construct a system dynamics model, select the main constraints of environmental factors in the Three Gorges Reservoir area, set three different development scenarios, and observe their impact on CODcr and determine the range of ecological safety thresholds.

1. Introduction

Ecological security refers to the health and integrity of the ecosystem, the ability of preventing the deterioration of environmental quality and prompting sustainable economic development. Its integrity, irreversibility, and long-term characteristics make the subsequent development of ecological security in the reservoir area directly affect the operation of the various functions of the Three Gorges Project.

At present, mathematical statistical models and system analysis methods are widely used in the study of water ecological security. Cai Zhongliang (2019) took the Three Gorges reservoir area in Hubei Province as an example to construct a comprehensive ecological security evaluation system, starting from three perspectives of ecological service capacity, ecological sensitivity, and ecological landscape pattern, and then derived the ecological security characteristics of the study area. [1] Tan Caihe (2019) analyzed the health of the ecosystem in the Chongqing section of the Three Gorges Reservoir area, and used the PSR model to evaluate the health which is more comprehensively and objectively. [3] The network analytic hierarchy process optimizes the analytic hierarchy process and is used in many fields. [3-4]

Through reading the previous literatures, the digital ground model method separate ecology from economic and social factors, fail to reveal the relationship between subsystems and the feedback between systems; Using static data statistical analysis models makes the relationship between ecological and environmental factors be ignored. The system dynamics method can simulate and analyze the changes of various factors in the system and simulate the long-term changes under different situations. ANP can better reflect the interaction between subsystems. In this paper, use the ANP method to find out the factors that have the greatest impact on ecological security, construct a system dynamics model and study the feedback mechanism and dynamic behavior of the system.
2. Methodology

2.1. Analytic Network Process
The network analytic method combines multiple indicators, comprehensively considers the relationship between different element groups and the relationship between different elements within the same group, mainly including control layer and network layer. The control layer is composed of decision indicators, criteria, and subsystems, and the network layer is composed of elements controlled by the control layer, and there are correlations between elements and element groups.

2.2. Determine Evaluation Index
There are two main aspects of ecological security in the Three Gorges Reservoir area: First, the ecological security problem at the natural level is reflected in the terrain and climate that cause serious soil erosion. Secondly, the ecological security problem at the social level mainly refers to the contradiction between man and land. Take five main factors in the Chongqing Three Gorges Reservoir area to form the sub-network; the selection of indicators follows the principle of correlation and refers to Zhang Mengjie’s research [5], as shown in the picture 1.

![Subsystem division system diagram](image1)

**Figure 1. Subsystem division system diagram**

3. Build an Evaluation Model
According to the evaluation indicators and their relevance, the network layer analysis method structure model as shown in the figure is established. The network layer includes 5 indicator groups, which are divided into water environment indicators W, policy indicators P, economic indicators E, population indicators H, and biological indicators B. Invite experts in the ecological field and more than 10 people in this research team to use the expert scoring method to determine the interrelationships between the various indicators of the subsystem network layer in each region.

![Structural Model of Subsystem Network AHP](image2)

**Figure 2. Structural Model of Subsystem Network AHP**
3.1. Solving and Analyzing Evaluation Model

3.1.1. Evaluation index weight

Using SuperDecisions software to calculate the weights of the evaluation system, combined with the expert scoring method, the weights of each evaluation index are obtained, as shown in Table 1.

| Secondary indicators | Weights | Third indicators                  | Relative weight | Global weight |
|----------------------|---------|-----------------------------------|----------------|---------------|
| Biological indicators| 0.173224| Benthic Biodiversity Index(B3)    | 0.21283        | 0.036868      |
|                      |         | Zooplankton diversity (B2)       | 0.21283        | 0.036868      |
|                      |         | Phytoplankton diversity (B1)     | 0.21283        | 0.036868      |
| Economic Indicators  | 0.270305| Per GDP(E1)                       | 0.09092        | 0.024577      |
|                      |         | Engel coefficient(E4)            | 0.04061        | 0.010978      |
|                      |         | Per capita income of river basin(E5) | 0.06819    | 0.018432      |
|                      |         | The total output value density of industrial and agricultural industries in the basin(E2) | 0.17800 | 0.048115 |
|                      |         | The proportion of tertiary industry output value to GDP(E3) | 0.11143 | 0.030119 |
| Demographic indicators| 0.108116| Urbanization rate(H1)            | 0             | 0             |
|                      |         | Population growth rate(H3)       | 0.25849        | 0.027947      |
|                      |         | Basin population density(H2)     | 0.25849        | 0.027947      |
| Policy indicators    | 0.153949| Rural domestic sewage treatment rate(P4) | 0.10453 | 0.016093      |
|                      |         | Centralized treatment rate of urban sewage(P3) | 0.10453 | 0.016093      |
|                      |         | Industrial wastewater treatment rate(P2) | 0.13643 | 0.021004      |
|                      |         | Soil erosion control rate(P5)    | 0.11193        | 0.017232      |
|                      |         | Environmental protection investment(P1) | 0.25609 | 0.039425      |
|                      |         | Environmental protection investment as a percentage of GDP(P6) | 0.28647 | 0.044102      |
| Water environment index| 0.294405| Chlorophyll(Chlo)(W2)            | 0.18401        | 0.054172      |
|                      |         | Total nitrogen(TN)(W4)           | 0.17889        | 0.052667      |
|                      |         | Total phosphorus(TP)(W3)         | 0.17889        | 0.052667      |
|                      |         | Water resources development and utilization rate(W8) | 0.01015 | 0.002987      |
|                      |         | River body(CODcr)(W1)           | 0.13345        | 0.039287      |
|                      |         | River runoff(W7)                | 0.03605        | 0.010614      |
|                      |         | Water resources per capita in the basin(W6) | 0.04512 | 0.013284      |
|                      |         | transparency(SD)(W5)            | 0.23344        | 0.068727      |

3.1.2. Weighted result analysis

It can be seen from Table 1 that the most important factor affecting ecological security in the secondary indicators is the water environment, with a weight of 29.4% and biological indicators, population indicators, and policy indicators are all less than 20%. Among the global weights of the third-level indicators, the transparency indicator has the greatest impact on the water environment layer, the weight is 6.87%, while the impact of the urbanization rate on the population is 0. In the biological layer, benthic biodiversity, zooplankton diversity, and phytoplankton diversity have the same influence on it, with the weight of 3.68%. Among the economic indicators, the weight of the total output value of the industrial and agricultural industries in the basin is the largest at 3%. In the
population layer, the proportion of environmental protection investment in GDP has the greatest impact on the policy level, with a weight of 4.41%. This paper selected many three-level indicators in the water environment layer, and the weight of water resources development and utilization rate is significantly lower than other indicators, only 0.2%.

4. Constructing a Dynamic Model of the Ecological Security System in the Chongqing Three Gorges Reservoir Area and Simulating Different Scenarios

4.1. Establishment and Verification of System Dynamics Model

4.1.1. Model establishment

System dynamics can quantitatively analyze various characteristics, and is good at handling high-order and nonlinear problems, and is suitable for objective long-term dynamic trend research. It can be expressed as a mathematical equation:

\[ y(t) = y(t-1) + R(t) + t \]

In the formula, \( y(t) \) is the quantity in time \( t \); \( y(t-1) \) is the quantity in time \( t-1 \); \( R(t) \) is the rate of change between time \( t-1 \) to time \( t \); \( t \) is interval time period. A variable rate equation represents a basic unit of system dynamics, and these basic units are connected in series to form a complete system dynamics.

There are two dominant causal feedback loops: (1) Negative feedback system: the total population increases and industrial development, leading to an increase in domestic sewage and industrial wastewater discharge, which in turn increases total energy consumption, nitrogen emissions, and phosphorus emissions, increases environmental burdens, reduces water resources quality in the Three Gorges reservoir area, and endangers soil health Degree, and ultimately hinder economic development. (2) Positive feedback system: The continuous increase in environmental protection investment will reduce the CODcr, P, and N content in wastewater. According to the above analysis, the system flow diagram of the system dynamics model is established as shown in the figure 3.

**Figure 3.** The causality diagram of the second and third levels of the subsystem

4.1.2. Test model robustness

In Figure 4, the error between the simulated value and the true value is within an acceptable range.
4.2. Setting and Simulation of Different Scene Parameters
This paper sets three different development scenarios and sets up the parameters according to the Chongqing Statistical Yearbook. The natural state type is the current value of the Chongqing Three Gorges reservoir area, the sustainable development type is the lower limit of the index, and the resource exhaustion type is the upper limit of the index. Select the main constraints of environmental factors in the Three Gorges Reservoir area, adjust the value ranges of these four items, and observe their impact on CODcr. The operating results are shown in the figure 5.

4.2.1. Result analysis
It can be seen from Figure 5(a) that when the environmental protection input rate is 1.8%, its impact on CODcr, N, and P gradually weakens during the study period, and these three chemical substances in the water body increases from 8mg/L to 13mg/L and tends to be stable. When the environmental protection input rate is 2.8%, the impact of its on the content of chemical substances in water is relatively limited. The content of CODcr, N, and P is between 8-10, and there is a downward trend after 2015 when the environmental protection input rate is 3.8%, the effect is the best at this time.

Figure 5(b) shows when the rural sewage treatment rate is 47%, the impact on the water body is the smallest, that is, the chemical substance content is the highest, and the impact is decreasing year by year. The degree of impact will reach a trough in 2020, and it is predicted that there may be almost no impact on water bodies after 2020. When the rural sewage treatment rate is 53%, there is a certain
Effect in the early stage of the study period, but the effect had weakened after 2015. When the rural sewage treatment rate is 57%, the treatment effect of water body chemicals is the best at this time, and the treatment rate maintains an upward trend as the years increase. Urban sewage treatment rate with different values (80%, 85%, 90%), the conclusion is the same as the rural sewage treatment rate. When the urban sewage treatment rate is set to 90%, the content of CODcr, N, and P increased slightly from 2010 to 2013, but then decreased significantly.

From Figure 5(d), it can be seen that the contents of CODcr, N, and P reached their peaks in 2016 under the three conditions of slow population growth, steady growth, and rapid growth, and then declined. The larger the population base, and the higher the content of the three substances in the water body, indicating that population growth has a negative impact on the water environment. In 2020, the content of CODcr, N, and P in water under conditions of rapid population growth will still be higher than that of CODcr, N, and P under conditions of slow population growth.

4.3. Determine the Threshold of Ecological Safety Indicators
Increasing investment in environmental protection and increasing pollution treatment rate can effectively improve the quality of water bodies. Model simulation shows that the best environmental protection investment rate is between 2.8% and 3.8%, the best rural domestic sewage treatment rate is between 53% and 58%, and the best urban sewage treatment rate is between 85% and 90.

5. Conclusion
The construction of the Three Gorges Project has caused varying degrees of damage to the ecosystem in this area. From the research results, it can be concluded that water environmental factors have the greatest impact on ecological security, followed by economic indicators, and the third-level indicators have a smaller impact on the second-level indicators.

Based on the geographical and environmental characteristics of the Three Gorges Reservoir area, this paper establishes an ecological security system dynamic model, and simulated resource exhaustion, sustainable development and natural state. The results show that sustainable development can effectively control environmental pollution. Therefore, this article puts forward several suggestions: 1. Increase the sewage treatment rate and appropriately increase environmental protection investment. 2. Regulate population growth and avoid exceeding the maximum carrying capacity of the environment.

6. References
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