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Resilience Evaluation and Regulation Model for Water Resources Systems Based on Artificial Intelligence and Next-Generation Human-Computer Interaction

Qian Li[1*] and Lun Li[2]

[1]HeNan Open University, School of Architectural Engineering and Intelligent Construction, Zhengzhou 450008, China
[2]Henan Province Rural Water Supply Station, Water Supply Division, Zhengzhou 450003, China
LunLI2023003@outlook.com

Corresponding author: Qian Li, QianLI202308@outlook.com

Abstract. The Water resources system has multi-dimensional characteristics. The indicators of the economic system are measured by the level of economic development and the level of fiscal expenditure. Among them, the economic development level is a measure of development level, which can effectively reflect the contribution of water resources, and the financial expenditure level can reflect the support and improvement of government departments for development. To promote the efficiency of resilience evaluation of water resources systems and improve water resources resilience, this paper combines artificial intelligence technology to build a resilience evaluation and regulation model for water resources systems. Based on dissipative structure theory, this paper puts forward a model based on information entropy. Using the standardized value of indicators to calculate the development coordination degree of a composite system, build a resilience evaluation and regulation model of water resources based on artificial intelligence, and combine intelligent algorithms to evaluate and analyze the resilience of water resources. Simulation research has verified that this method has specific effects, and this paper puts forward several pertinent suggestions.

Keywords: artificial intelligence; water resources; resilience; regulation model; next-generation human-computer interaction.
DOI: https://doi.org/10.14733/cadaps.2024.S20.65-78

1 INTRODUCTION

With the deepening of research in the field of water resources and environment and the improvement of people's cognitive levels, scholars have introduced the concept of "resilience" to study the ability of the water resources system to resist pressure and recover its state. The resilience of the water resources system emphasizes the ability to resist disturbance, adapt to the changes brought by disturbance, and achieve a better state when the water resources system and its functions are disturbed by nature or human beings [4]. This research idea is still in its infancy, and scholars mainly enrich the theory of water resources system resilience from the perspective of expanding the connotation of water resources system resilience. Among them, many scholars define the resilience of the water resources system from the flood risk management perspective. For example, some scholars define the resilience of the water resources system from different perspectives, such as a single building, city, watershed, and region [13], emphasizing the ability of the water resources system to resist natural disasters and recover after disasters.

The resilience of water resource systems has process attributes. Based on whether the original system state has changed, the process of changing the strength of water resource systems can be divided into three stages [15]: ⊖ Before the actual state changes: natural or human activities cause interference to the system and face degradation pressure; ⊜ In the process of changing the original state: due to interference, the state of the water resource system changes, which in turn drives a change in the state of the entire ecological environment system to which it belongs; ⊛ After the original state is changed, through manual adjustment and system adaptation, the system absorbs interference and reaches a new and more optimal state. In the process of evaluating resilience in existing research, the standard approach is still only to construct an indicator system based on the three significant characteristics of resilience: resistance, resilience, and adaptability [1], or to decompose the water resource system into subsystems such as economy, society, and ecology, focusing on observing the impact of various elements between different systems on resilience [19], while ignoring the process attributes of resilience. In the field of resource and environmental research, in addition to resilience analysis, there is also a commonly used research paradigm: the "Pressure State Response" (PSR) model, which explores the dynamic connection between ecological environment systems and socioeconomic systems by studying the interaction process between stress, state, and response levels [16]. Among them, pressure refers to the load caused by human socioeconomic activities and nature itself on the ecological environment; state refers to the state and changes of the natural environmental system; and response refers to a series of ecological governance measures taken by humans to improve the environmental state [11]. This model reflects the process of human activities or nature exerting pressure on the natural environment, affecting the natural environment and resources. Human beings respond to the pressure to improve the natural environment's state and reduce its pressure [8]. Because the process of resilience change in water resource systems is a typical "pressure state response" process, using the PSR model for resilience evaluation can better measure the process of water resource systems being impacted by pressure, changing their state, restoring their original state, and achieving a better state from the perspective of resilience change, making up for the shortcomings of existing research.

In all cases, the focus is on how the system responds to unexpected load situations [2]. The goal of resilient systems is to withstand failures as much as possible and recover from them in the event of a failure. In this study, the water resource system in irrigation areas can be seen as a system formed by the interaction between the canal well (water supply facility) subsystem and the ecological (crop, climate) subsystem. The resilience of the water resource system in irrigation areas can be defined as the ability of the system to resist drought through effective allocation of water volume and recharge of groundwater in the face of drought [12].

The concept of resilience in urban water management is widely valued in both academia and industry. In recent years, enhancing the resilience of water resource systems and effectively addressing system vulnerabilities have been widely recognized and applied by researchers and practitioners. Reference [10] incorporated resilience into the evaluation and management of urban floods and proposed a resilience evaluation index based on grid units, comparing the flood control capabilities of different catchment areas. Literature [17] evaluated the efficiency and resilience of the water resources system in the resilient region of the water resources system and the development coordination relationship between them, discussed the research methods in the assessment of the resilience of the urban water supply system under the influence of the salt tide scenario, established the urban water supply system resilience assessment index system based on engineering, economy, resources, cities, and other aspects, and absorbed The visual simulation evaluation results of three system capabilities, including adaptability and resilience, as well as system resilience, have identified areas where urban water supply systems are relatively fragile. This provides a theoretical basis and decision-making support for further disaster prevention and reduction, as well as improving the quality level of water supply system resilience.

The efficiency of water resources can be analyzed through their connotation in terms of resource efficiency. In the initial analysis process, the analysis and measurement of water resource efficiency are only conducted economically, that is, how much economic benefit is generated by the utilization of unit water resources, how much output is made for the improvement of GDP, and how much more benefit is generated by using as few resources as possible. This analysis method is called the economic efficiency of water resources and belongs to the single factor of resource efficiency. Single-factor Resource efficiency only focuses on the minimum energy consumption per production unit while ignoring other factors in the production process. Based on these shortcomings, researchers propose the concept of environmental technology efficiency from the investment perspective, which differs from traditional efficiency concepts. The new concept reflects the changing relationship between input, output, and a polluted environment and includes the constraints of environmental pollution on development under the new concept. Therefore, the impact of different resource utilization methods under current conditions is analyzed. Researchers have again proposed a function to characterize the relationship between different outputs, called the environmental directional distance function [14]. This function can more clearly reflect the distinction and connection between the output of good products and by-products. Resource efficiency represents the coordinated development of regional water resources and environment and demonstrates the rationality and effectiveness of human use and development of water resources in a particular region. On this basis, experts and scholars began to pay attention to the total factor of resource efficiency. Its measurement method is a measurement method that calculates the input and output of multiple factors in the genuine factor. Production function comprehensively considers the impact of interaction between various input factors on resource utilization efficiency. It improves the traditional measurement method of single-factor Resource efficiency, which can be more objective and accurately evaluate the resource utilization level of a country or region [18].

Literature [6], based on a review of theories related to healthy ecosystems, suggests that healthy ecosystems typically lack detectable pathological symptoms. A healthy ecosystem can absorb more stress loads, but its ability to cope with stress will inevitably decrease as the load increases. The aquatic ecosystem is a part of nature and a relatively independent ecosystem. As a subsystem of the ecosystem, it has multiple levels and subsystems. With various factors such as industrial pollution and deforestation putting enormous pressure on the health of water ecosystems, studying water ecosystem health has become particularly important, and its field has broad application prospects. Due to the different focuses of scholars' research and the abstract nature of water ecosystems, they have different understandings of water ecosystem health [3]. According to the literature [5], many organisms are in a healthy aquatic ecosystem and relatively balanced state, so introduced species invasion and species disappearance will not occur. Reference [9] believes that water ecosystem health refers to the similarity between the current state of the water ecosystem and the original state of the water ecosystem, mainly compared from two aspects: one is the integrity of organisms, and the other is the function of ecology. Reference [7] suggests that the health of water ecosystems should consider the ecological structure of water itself and the impact of social life and human activities on water ecosystems. From the perspective of water ecosystem management, literature [20] suggests that a healthy water ecosystem should have a specific remediation capacity. Water ecological remediation aims to create a healthy environment and comprehensively analyze the water body's microorganisms, chemistry, and other aspects to reflect the overall environmental function.

To promote the efficiency of resilience evaluation of water resources systems and improve the resilience of water resources, this paper constructs a regulation model of water resources system resilience evaluation combined with artificial intelligence technology. It analyzes its practical effect on improving water resources governance strategies' application effect effectively.

2 RESILIENCE EVALUATION OF THE WATER RESOURCES SYSTEM

2.1 Calculation and Analysis of Resilience and Efficiency of Water Resources System

By constructing the evaluation index system for the resilience and efficiency of the water resources system, water resources' utilization efficiency and carrying capacity are improved. Resources and environmental factors are measured in water resource endowment and ecological pressure.

Input index: The cultivated land area, chemical fertilizer application, water consumption, primary industry employees, and total mechanical power in the system are selected as the input index of the SBM-DEA model.

Expected output: GDP (based on GDP in 1990) and social development index are selected as desired output, among which the Social Development Index (SDI) can comprehensively and scientifically reflect social development, not only referring to economic development level but also including people's livelihood and social security, which is in line with China's current construction goal of high-quality development. An index system including urbanization development level, science and technology level, education and education level, medical security level, and consumption level is formulated. The calculation process for the social development index is as follows:

Normalization of the high-quality index is:

$$S'_{\mathrm{km}} = \frac{S_{\mathrm{km}}}{max(S_k)} \times 100\% \tag{1}$$

Normalization of the low excellent index is:

$$S'_{\mathrm{km}} = \frac{min(S_k)}{S_{\mathrm{km}}} \times 100\% \tag{2}$$

In the formula, S_{km} refers to the original value of the k-th item in the m-th year, S_k refers to all the actual data values of the k-th item in the research period, $max(S_k)$refers to the maximum value of all the original data of the k-th item in the research period and$min(S_k)$refers to the minimum value of all the original data of k-th item in the research period.

$$SDI = \frac{1}{t} \sum S_{\mathrm{km}}{}' \tag{3}$$

Unexpected output: The intensity of the grey water footprint is selected as the random output.

2.2 Measurement Method

To realize the unity of subjectivity and objectivity and ensure the scientific and rational setting of index system weights, the weights of the index system of resilience and efficiency of the water resources system are determined by the subjective and objective weighting methods and the initial weights are determined by the analytic hierarchy process (AHP). Then, the accurate weighting method, the entropy method (EVM), determines the comprehensive weights.

1. Analytic Hierarchy Process (AHP)

Firstly, the resilience index system of the water resources system is decomposed hierarchically. Each subsystem of the economy, society, resources, and environment is determined as the target layer. Then, the development space and investment of economic factors are investigated from the level of economic development and financial expenditure, the social factors are measured from the four angles of scientific and technological innovation ability, population development and infrastructure level, and the resources and environment factors are explored from the two aspects of water resources endowment and pressure. They are determined as the criterion layer, and the measurement factors are defined as the index layer through detailed index reflections.

The judgment matrix S is constructed:

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{n1} & s_{n2} & \cdots & s_{nn} \end{bmatrix} \tag{4}$$

The product H_i of each row of the judgment matrix of the target layer is obtained, and the n-power root $\bar{Q}_i$ of the result is calculated:

$$H_i = \prod_{j=1}^{n} s_{ij} \; (i = 1,2,3, \ldots \ldots, n) \tag{5}$$

$$\bar{Q}_i = \sqrt[n]{H_i} \tag{6}$$

$\bar{Q}_i$ is normalized to get the weight Q_i:

$$Q_i = \frac{\overline{Q_j}}{\sum_{j=1}^{n} \overline{Q_j}} \tag{7}$$

The maximum eigenroot $\lambda_{\max}$ is calculated as:

$$\lambda \sum_{i=1}^{n} \frac{(\mathrm{SQ})_i}{nQ_i}{}_{max} \tag{8}$$

The consistency index is calculated as follows:

$$CI = \frac{\lambda_{max}}{n-1} \tag{9}$$

The consistency ratio is calculated as follows:

$$CR = \frac{CI}{RI} \tag{10}$$

In the formula, RI represents the average random consistency index.

2. Entropy method (EVM)

The entropy method determines the weight by calculating the relative change degree of each index in the index system. It determines the influence of each index on the resilience of the water resources system in the Yellow River Basin. This method is objective.

The data of indexes are standardized:

$$X'_{ij} = \frac{X_{ij} - min\{X_j\}}{max\{X_j\} - min\{X_j\}} \tag{11}$$

Positive i indicator

$$X'_{ij} = \frac{max\{X_j\} - X_{ij}}{max\{X_j\} - min\{X_j\}} \tag{12}$$

Negative i indicators:

$$Y_{ij} = X'_{ij} + 0.00001 \tag{13}$$

The proportion of each index is calculated by entropy method:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{14}$$

The entropy value and entropy redundancy of the index is calculated:

$$e_j = -\frac{1}{ln(n)} \sum_{i=1}^{n} p_{ij}\, ln\, p_{ij} \tag{15}$$

$$d_j = 1 - e_j \tag{16}$$

The initial index weight is calculated:

$$Z_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{17}$$

The result deviation is reduced:

$$min\, D\,(a) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left\{ \left[(Z_j - A_j) Y_{ij} \right]^2 + \left[(Q_j - A_j) Y_{ij} \right]^2 \right\} \tag{18}$$

$$\sum_{j=1}^{n} A_j = 1, A_j \geq 0 (j = 1,2, \dots, n) \tag{19}$$

The comprehensive score is:

$$K = \sum_{i=1}^{n} A_i Y_{ij} \tag{20}$$

DataEnvelopmentAnalysis (DEA) is a method to measure the relative efficiency, which can compare the efficiency of different decision-makers. The DEA model can be divided into two types: The radial model and The non-radial model. Among them, The radial model measures input and output according to a particular proportion, but there will be insufficient output or surplus input in actual situations. Therefore, a non-radial model is usually selected to calculate scientifically and rationally. Using a non-radial and non-angular SBM model based on relaxation variables, the calculation results of the SBM-DEA model are more suitable for the actual water resource utilization efficiency in the study area.

$$\rho = min \frac{1 - \frac{1}{N} \sum_{n=1}^{N} s_n^x / x_{k'n}^{t'}}{1 + \frac{1}{M+1} \left(\sum_{m=1}^{M} s_m^y / y_{k'm}^{t'} + \sum_{i=1}^{I} s_i^b / b_{k'i}^{t'} \right)} \tag{21}$$

$$\text{s.t. } \sum_{t=1}^{T} \sum_{k=1}^{K} z_k^t x_{kn}^t + s_n^x = x_{k'n}^{t'} (n = 1, \dots, N) \tag{22}$$

$$\sum_{t=1}^{T} \sum_{k=1}^{K} z_k^t y_{km}^t - s_m^y = y_{k'm}^{t'} (m = 1, \dots M) \tag{23}$$

$$\sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t\, b_{ki}^t + s_i^b = b_{k'i}^{t'} (i = 1, \dots, I) \tag{24}$$

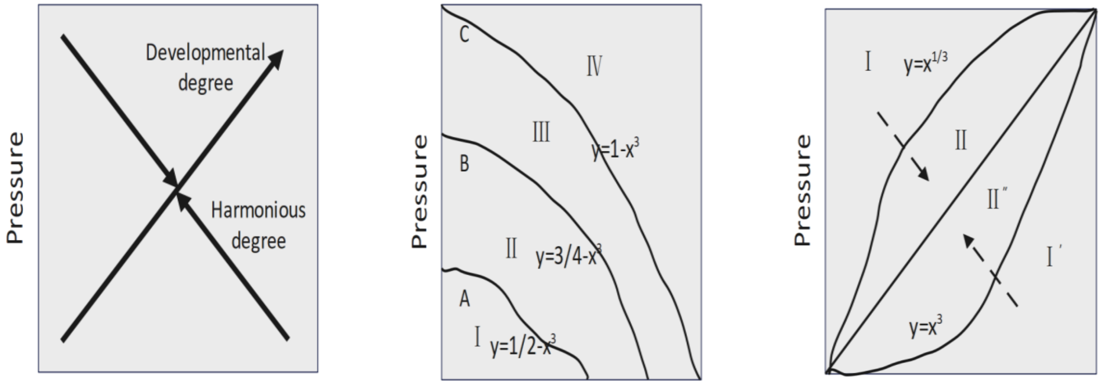
$$z_k^t \geq 0, s_n^x \geq 0, s_y^m \geq 0, s_i^b \geq 0 (k = 1, \dots . K) \tag{25}$$

The formula ρ represents the water resource efficiency calculated according to the collected data. N (input index), M (expected output index), and I (unexpected output index) represent the number of indexes, which are respectively by 5,2,1; $(s_n^x, s_m^y, s_i^b)$is the relaxation vectors of input and output; $\left(x_{k'n}^{t'}, y_{k'm}^{t'}, b_{k'i}^{t'}\right)$ is the input-output value of a the-production unit in t' period, and z_k^t is the weight. The closer ρ is to 1, the higher the efficiency.

2.3 Coordination and Development Analysis of Resilience and Efficiency of Water Resources System

Based on the dissipative structure theory, a model based on information entropy is proposed, and the development coordination degree of a composite system can be calculated using the standardized value of indicators, referred to as the quantitative model of development coordination for short.

Figure 1 (a) depicts possible trends in development and harmful levels, and Figure 1 (b) shows possible boundaries of economic development. Ecosystem carrying capacity and economic development pressures are opposite processes in ecosystems. Figure 1 (b) shows that limited resources and a lack of advanced technology will limit economic activities, and curves $A, B, and\ C$ are predictive development functions. In Figure 1 (c), the square area is divided into four equal parts by three curves $(y = x$、 $, y = x^3$, $y = x^{1/3})$, which reflect the degree of coordination with natural subsystems. The degree of coordination is divided into four standard grades for easy comparison: intense socioeconomic pressure (II), a medium socioeconomic pressure (I), medium ecological carrying capacity (I'), and environmental solid carrying capacity (II´).



(a) (b) (c)

Figure 1: Degree of development and coordination.

Based on the above theory, a quantitative model of coordination and development of the resilience and efficiency of the water resources system in the study area is constructed (Figure 2). The development curve reflects the nonlinear relationship between water resources system resilience and utilization efficiency, and the curve division method reflects the dynamic changes of the water resources system and then explores the coordination relationship between water resources system resilience and utilization efficiency. Among them, the degree of development is represented by D, and the closer it is to 1, the better the degree of development, and they are developing in a good direction. The value is between 0-1, and the coordination degree is represented by C; the higher it is, the higher the degree of mutual promotion, and its value is also between 0-1. The development coordination degree is represented by T, which refers to the degree to which the friendly interaction between resilience and efficiency in the water resources system develops in a more orderly direction.

Degree of development:
$$D = y + x^3 \tag{26}$$

Degree of coordination:
$$C = log(y)/log(x) \tag{27}$$

Degree of development and coordination:
$$T = \sqrt{D \times C} \tag{28}$$

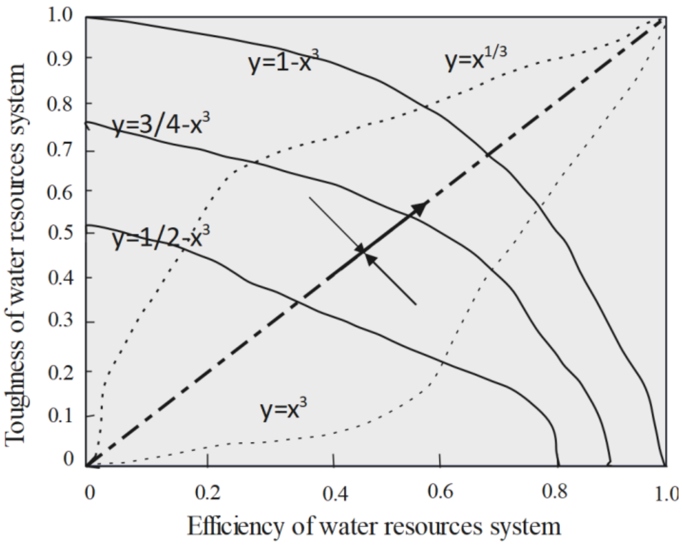


Figure 2: Quantitative model of development coordination.

3 MODEL CONSTRUCTION

The Water resources system and its ecological environment system provide resources for human society, and human activities and natural fluctuations (including natural disasters) impact the water resources system, causing pressure and changing the state of the water resources system and its ecological environment system. The resilience of the water resource system is shown in Figure 3.

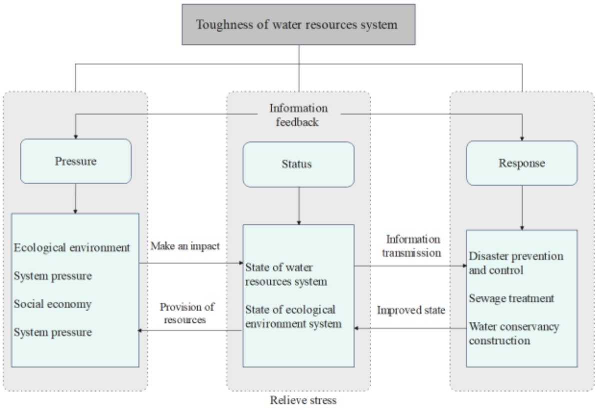


Figure 3: Resilience diagram of water resources system.

This paper analyzes resilience from the dynamic perspective of "pressure →status → impact response." The specific research framework is shown in Figure 4.

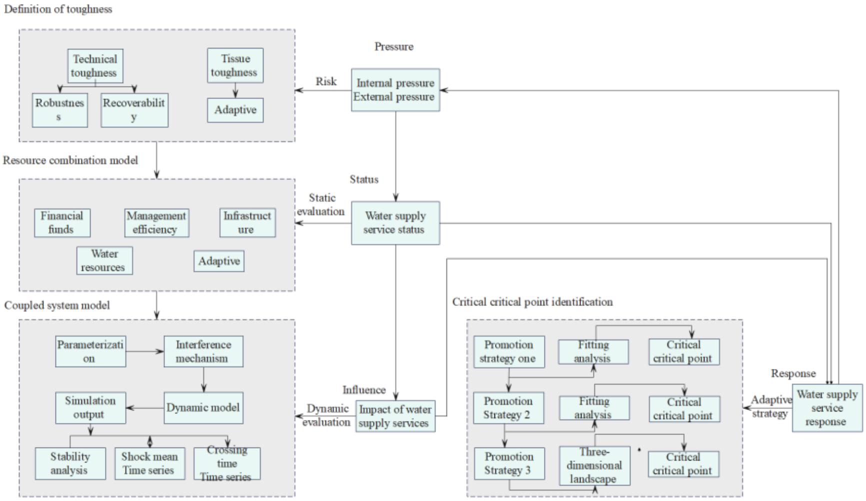


Figure 4: Research framework of water resources resilience.

Because many variables affect resistance (resilience or adaptability), it is challenging to analyze the functional relationship between them quantitatively. This study converts a multi-dimensional index into a one-dimensional one using dimension reduction in projection pursuit. It makes it simple to study further the functional relationship between resistance (resilience or adaptability) and the evaluation index. For the projected configuration, the dimensionality reduction function is used to measure the possibility of launching a specific structure, and the value that maximizes the square of the standard deviation of the dimensionality reduction function is found. Then, according to this value, the structural characteristics of high-dimensional data are analyzed, as shown in Figure 5.

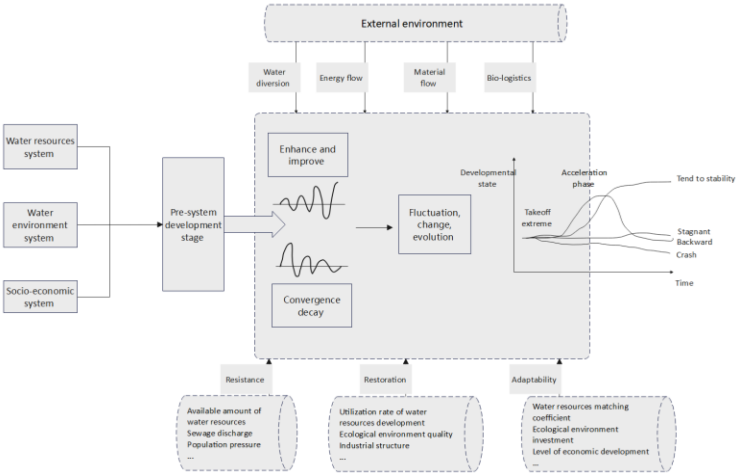


Figure 5: Resilience evaluation index system of a complex system.

The system is divided into three parts: the data acquisition, communication, and cloud data management systems. Moreover, each part plays an important role, and the coordination of the three is indispensable. The overall architecture of the system is shown in Figure (a).

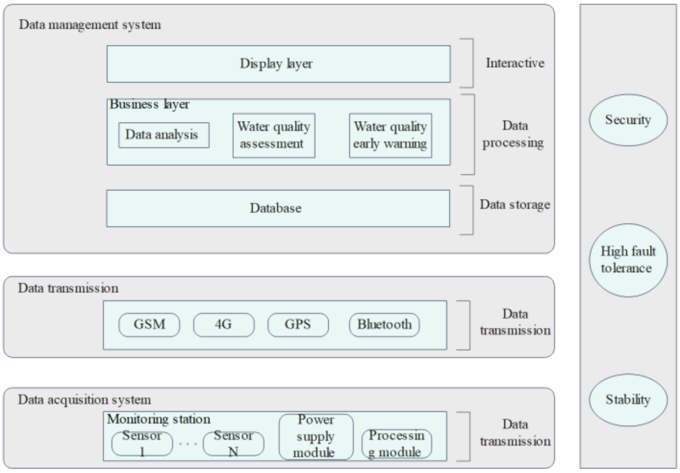
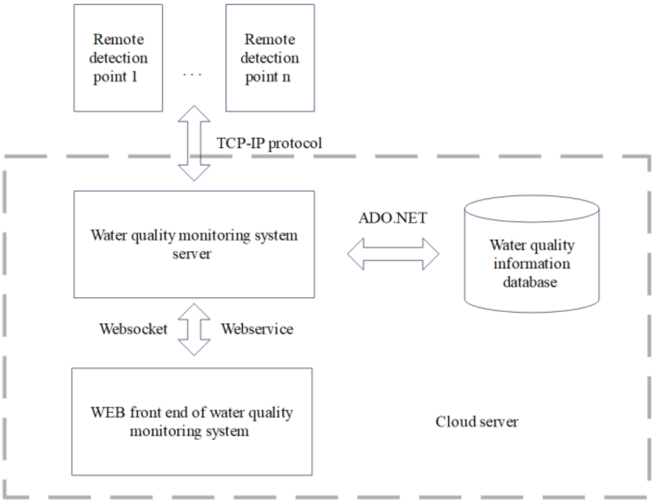
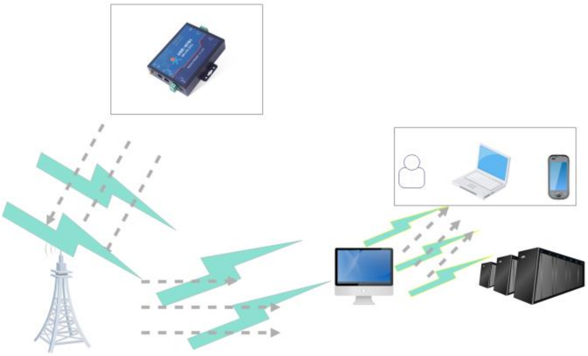


Figure 6: System architecture.

Transmission Control Protocol/Internet Protocol (TCP/IP) is a general Internet information transmission protocol. The communication system is mainly responsible for communication connections and data transmission among subsystems, equipment, and applications of the whole monitoring system. The communication protocols of each part of the system are shown in Figure 7 (a), and the communication information flow of the system is shown in Figure 7 (b).



(a) Communication protocol diagram of each part of the system

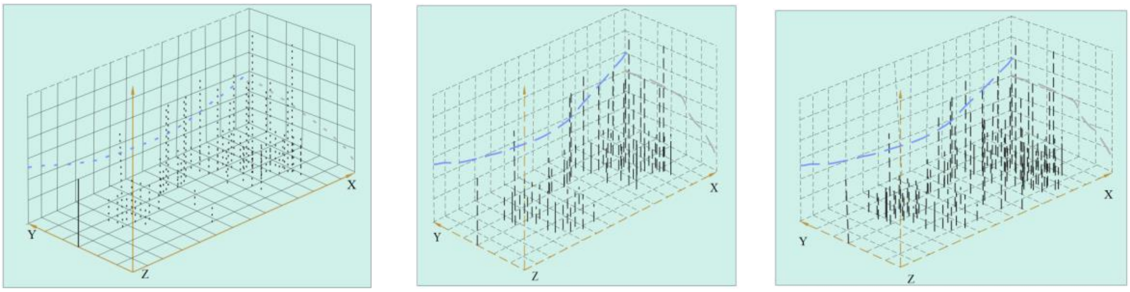


(b) Communication Information Flow Diagram

Figure 7: Communication schematic diagram.

4 MODEL VALIDATION

To verify the effectiveness of this model, this paper selects a river as the research object. It uses the trend analysis tool in ArcGIS10.2 to depict the spatial distribution trend of urban water resources system resilience in 2014, 2018, and 2022 (Figure 5). Among them, the Z axis represents the resilience index of the urban water resources system, the lines on the X axis correspond to the changing trend of the resilience index of the urban water resources system in the east-west direction, and the lines on the Y axis correspond to the changing trend of the resilience index of urban water resources system in the north-south direction.



(a)2014 (b)2018 (c)2022

Figure 8: Simulation analysis diagram of resilience index of water resources system.

Based on the above model analysis, the dynamic lifting process of a specific toughness state is put forward, as shown in the triangular model of the system toughness lifting path in Figure 9. In a rigid trap, managers concentrate resources and efforts to adapt to specific external pressures and internal needs. This leads to a highly interrelated and self-reinforcing water supply system (for example, highly centralized and resilient water supply facilities). At the same time, the vast sunk cost and the legacy impact caused by the centralized and resilient water supply infrastructure seriously hinder adaptive management. Finally, the system falls into a vicious circle of high recoverability → low robustness → high recoverability.

5 CONCLUSIONS

Although there are different definitions of resilience in current studies, most are based on the evolution of adaptive theory, assuming that the system can recover to its original stable state after being disturbed. That is, a revitalized system can withstand shocks and rebuild itself. At present, the unified concept of system resilience in research is that resilience is the ability of the system to recover to a stable state after being disturbed. Water resources utilization efficiency is the ratio of expected and unexpected output brought by the combination of water resources and related elements, and water resources utilization efficiency refers to the ratio of water resources, labor, and other related production factors to bring expected and unexpected outputs. This paper puts forward countermeasures to improve the resilience and utilization efficiency of the water resources system in the study area from the aspects of perfecting policies and measures, improving planting structure, promoting water consumption to reduce pollution and carbon, and strictly managing the water use process to rationally develop and utilize water resources and adjust agricultural water use structure. The model of water resource resilience evaluation and regulation based on artificial intelligence is constructed, and the review and analysis of water resource resilience are combined with the algorithm in the second part. The simulation research verifies that the method in this paper has specific effects and puts forward several targeted suggestions. This adaptation hinges on incorporating human-computer interaction sensitivity into the model's design and application. This involves understanding local practices, engaging communities, and tailoring the technology to accommodate linguistic and human-computer interaction variations. By doing so, the adapted model can offer insights that align with different cultural contexts' specific needs and priorities.

Qian Li, https://orcid.org/0009-0005-7839-4032
Lun Li, https://orcid.org/0009-0001-4971-3146

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