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Evaluation and Plan for Water Resources Carrying Capacity

Abstract

In this paper, we not only construct a static evaluation model to measure the water resources carrying capacity of a region based on entropy weight method, but also build a dynamic model to study the intrinsic mechanism of the water cycle in this region. Then we choose Jiangsu province in China as our research case, and analyze the reason of water scarcity in each city of Jiangsu. After that, we predict the water situation in next 15 years using the dynamic model, in addition we explore the impact of climate on our model. We deem that the water scarcity is very heavy in Jiangsu. Finally, we design a series of intervention plans for Jiangsu and conclude that we can relieve the pressure on local water resources but cannot make the region become less susceptible to water scarcity by simulation.

In the static evaluation model, it is not accurate to only use the water resource utilization rate to measure the usage of water resources. So we come up with *Coordination Coefficient* to measure the use of water, and then analyze the reason of water scarcity according to the coordination coefficient. We also provide a measure to confirm the type of water scarcity, and conclude that water scarcity is very heavy in Jiangsu and its type is physical scarcity.

In the dynamic model, we establish a series of differential equations according to water-cycling system in Jiangsu province. Using the least square method to fit the differential equations and we obtain the result that the per capita water supply in Jiangsu province is only $386.3m^3$ by 2029, a decrease in value almost 12.9% compared to that of 2014. Meanwhile, we find that the change has caused great influence on industrial water and domestic water, but has less impact on agriculture.

Afterward, we put forward five types of intervention plans, we not only study the effects of the intervention program, but also compare the quality of each plan. We find that we use desalinization plants and rainfall harvesting to alleviate the situation of water scarcity, it has resulted in a positive impact on the whole water ecosystem.

In the end, we establish a multi-objective optimization model to project water availability. And we have a rough estimate of the time when a critical issue occur, the time points in five intervention plans are 2036,2041,2067,2048, 2057.

We also make a sensitivity analysis for the static evaluation model and a stability analysis based on linear for the dynamic model. Through previous analysis, we can see that our model can be applied to many regions to study the situation of water.

Key Words: Static evaluation model, Entropy method, Dynamic model, Multi-objective optimization, Coordination Coefficient

Contents

1. Introduction

1.1. Background

The United Nations, the world water development report, shows that increasing demand for food, rapid urbanization and climate change have increased the pressure of global water supply.

1.6 billion people(one quarter of the world's population) experience water scarcity. By the middle of this century, agricultural water demand will increase by more than 19%, while the current agricultural water has accounted for 70% of the amount of fresh water [1]. Global climate change has intensified the world's water resources and has a significant impact on water supply and demand, the allocation and scheduling of water.

In general, humans require water resources for industrial, agricultural, and residential purposes. There are two primary causes for water scarcity: physical scarcity and economic scarcity. Physical scarcity is where there is inadequate water in a region to meet demand. Economic scarcity is where water exists but poor management and lack of infrastructure limits the availability of clean water. What's more, the increasing rates of personal consumption, or increasing rates of industrial consumption, or increasing pollution which depletes the supply of fresh water.

1.2. The Restatement of Problem

At first, we are required to develop a model that provides a measure of the ability of a region to provide clean water to meet the needs of its population. We deem that a region to provide clean water to meet the needs of its population is the water resources carrying capacity. In our model, we need to consider the dynamic nature of the factors that affect both supply and demand in our modeling process.

Then, we need to explain why and how water is scarce in the region that we picked where water is either heavily or moderately overloaded by addressing physical and economic. Besides, using our model to show what the water situation will be in 15 years is necessary. In order to accomplish this task, we maintain that the water situation is the change of supply and demand of water resources over time. Last, for our chosen region, we are required to design an intervention plan taking all the drivers of water scarcity into account and discuss the effect of our intervention on our chosen region's and the surrounding area's water availability. Be sure to detail the strengths and weaknesses of our model.

1.3. Previous Work

Develop a model to measure the ability of a region to provide clean water to meet the needs of its population, which is similar to evaluate the water resources carrying capacity of a region. It has formed a lot of quantitative research methods. The main measures include index-system method, ecological footprint, multiple-objective analysis, system dynamics and so on [2].

- Index-system method

For getting composite index, index-system method to compare the specific value of the evaluation index and the standard value of the comparison. In the evaluation of the water environment capacity, index-system method main includes vector modulus method [3], fuzzy comprehensive evaluation [4], AHP, PCA etc.

From the table 1, we can see that each method has its own advantages and limitations.

- Ecological footprint

The first academic publication about ecological footprints was by William Rees in 1992. The ecological footprint concept and calculation method was developed as the PhD dissertation of Mathis Wackernagel, under Rees' supervision at the University of British Columbia in Vancouver, Canada, from 1990–1994 [5]. Ecological footprint method has the advantages of strong operability and specification, but it tends to regional ecological sustainability, while ignoring the economic, social, technological and other aspects of the sustainable development of the environmental carrying capacity.

Table 1: Advantage and disadvantage of methods

Method	Advantage	Disadvantage
Vector modulus method	Simple and practicable, intuitionistic	Ignore the direction of the vector and the weight of index
Fuzzy comprehensive evaluation	Considered the fuzziness and uncertainty of index	Easy to lose information and cause miscarriage of justice
AHP	Combination of qualitative and quantitative analysis, easy to learn and use	Having strong subjectivity
PCA	Suppress interference and determine the dominant factor, easy analysis	There are some difficulties in the analysis standard of evaluation parameters

- Multiple-objective analysis

Multiple-objective analysis is to select these factors (e.g. society, economy, population and environment) that can reflect the water environment capacity, through the principle of sustainable development, to seek the overall optimization of a method. However, this method has a lot of deficiencies, such as the result is difficult to solve.

1.4. Model Overview

We have constructed a static evaluation model to measure the water resources carrying capacity of a region based on entropy weight method. Then, we build a dynamic model to study the intrinsic mechanism of the water cycle in a region. We chose Jiangsu province in China as our research case, and analyze the reason of water scarcity in each city of Jiangsu. After that, we predict the water situation in next 15 years using the dynamic model, and we focus on the impact of climate on our model. Finally, we design a series of intervention plans for Jiangsu and conclude that the region cannot become less susceptible to water scarcity by simulation.

2. Assumption

- **The ability of a region to provide clean water to meet the needs of its population is the water resources carrying capacity.**

Because humans require water resources for industrial, agricultural, and residential purposes.

We think that the ability of a region to provide clean water to meet the needs of its population is the water resources carrying capacity.

- **The water situation is the change of supply and demand of water resources over time.**

We think that the simple evaluation of water cannot directly show the change of water resources in a region, so we deem that the water situation is the change of supply and demand of water resources over time. Only in this way, can we quantitatively demonstrate the situation of water in a region.

- **All the data is comparatively valid.**

Because the data come from internet, we cannot ensure the facticity of each data. So we raise this assumption, to smoothly develop our modeling.

- **The growth date of crop is proportionate to the crop water requirement**

Although a little unreasonable, but in order to make quantitative calculation in our model, we believe that this assumption is feasible.

- **The temperature will increase one degree in the next 15 years.**

According to the change of temperature in the past, we assume that the temperature will increase one degree in the next 15 years. As a matter of fact, we can predict the change of temperature in the next few years by fitting.

- **We assume that the total water content in the dynamical system remains constant.**

In the kinetic model, we divided the water into 9 types, we assume the total water is constant and the value is equal to $1774\times10^8 m^3$.

- **Industrial sewage can be divided into two categories**

In the industrial waste water cycle, we deem that the lightly polluted sewage can be recycled, but the heavily polluted sewage cannot be recycled.

3. Notions

The variables and constants used in this paper are listed in **Table 2.**

Table 2: Notions

Symbols	Definitions
X	Initial data matrix X
x_{ij}	The value of the i-th sample and j-th indicator
x_j^*	The ideal value of j indicator
x_{ij}'	The standardization of x_{ij}
y_{ij}	Standardized matrix
e_j	The entropy of information of the indicator
K	It is constant and related to the system samples
d_j	The information utility value
w_j	The weight of indicator
S_i	Score of evaluation

CV_i	It represents the coefficient of variation of simple i
C_i	Coordination Coefficient
$A(t) \sim I(t)$	The ratio of each state to total water volume
α_i	The parameter of each change of states
λ_1	The utilization ratio of water resources
λ_2	Per capita water supply

4. Our Model

4.1. Question Analysis

In this part, we focus on how to develop a model that provides a measure of the ability of a region to provide clean water to meet the needs of its population. As a matter of fact, humans require water resource for industrial, agricultural, and residential purposes. These involve three aspects consist of society, economy and environment, so we determine to build a model to measure of the ability of supply and demand of water from these categories.

4.2. The Principle of Evaluation

- Good representative

The selected indicators can reflect the characteristics of a particular aspect, and the index system composed of the selected indicators can reflect the characteristics of all aspects of the evaluation object.

- Independence

In order to avoid the repeated information impact results.

- Easy to quantify and find
- The combination of dynamic and static index

Because the development of water resources system is changing over time, so indicators should be both dynamic indicators and static indicators.

4.3. Evaluation Model Based Entropy Weight Method

In the comprehensive evaluation, entropy of information is now in widespread use to estimate the degree of order of information and the utility of information. [7] To build a model that can provides a measure of the ability of region to provide clean water to meet the needs of its population.

4.3.1. Standardization of Data

Firstly, we need to deal with indicators. We suppose that the ideal value of j indicator is x_j^* which vary from index to index. For the Positive indicator, let the ideal value to be $x_{j\max}{}^*$.

For the Negative indicator, let the ideal value to be $x_{j\min}{}^*$. So we can find the ideal value of the indicator from initial data matrix X . Next, we define the standardization of x_{ij} which is recorded as $x_{ij}^{'}$.

- Positive indicator: $x_{ij}^{'} = x_{ij} / x_{j\max}^{*}$
- Negative indicator: $x_{ij}^{'} = x_{j\min} / x_{ij}$

The value of $x_{ij}^{'}$ range from zero to one, we can get standardized matrix $y_{ij} = \left\{ x_{ij}^{'} \right\}$.

4.3.2. Calculation of Weight

Then, According to Entropy Weight Method, we define the entropy of information of the indicator j

$$e_j = -K \sum_{i=1}^{m} y_{ij} \ln y_{ij} \tag{4.1}$$

Where, K is related to the system samples and it is constant. As to a system that is completely disordered, the degree of order is equal to zero and the entropy up to maximum. When $e=1$, $y_{ij} = \frac{1}{m}$, and

$$K = 1 / \ln m \tag{4.2}$$

The information utility value of a certain index depends on the difference between e_j and 1:

$$d_j = 1 - e_j \tag{4.3}$$

So based on Entropy Weight Method, we can get the weight of indicator j is:

$$w_j = d_j / \sum_{j=1}^{m} d_j \tag{4.4}$$

4.3.3. Score of Comprehensive Evaluation

$$S_i = \sum_{j=1}^{n} w_{ij} \times x_{ij}^{'} \tag{4.5}$$

We can calculate the score of evaluation, and this score can measure the ability of a region to provide clean water to meet the needs of its population.

4.4. Dynamic Model for Intrinsic Mechanism of Water

It is just a macro evaluation that measure the ability of a region to provide clean water to meet the needs of its population according to the indicators of water resources in a region. As a matter of fact, a region of water resources is a dynamic process of change, which can form a water cycle system. In order to measure the dynamic change process of clean water, we construct the kinetic equation by analyzing the conversion mechanism of water cycle in a region.

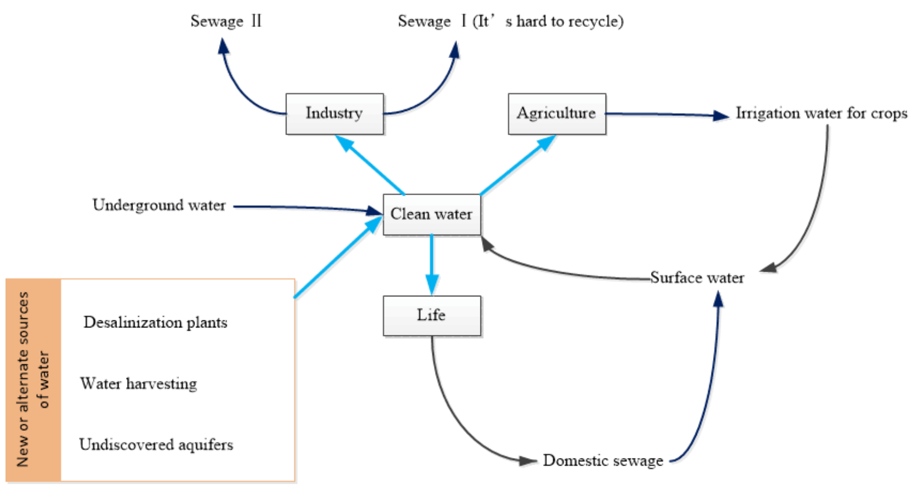

Figure 1: Conversion mechanism of water

From the figure of conversion mechanism of water, we can construct water-cycling system, then we could list the following differential equations.

$$\frac{dA(t)}{dt} = -\alpha_1 A(t)$$
$$\frac{dB(t)}{dt} = \alpha_9 E(t) + \alpha_{11} I(t) - \alpha_2 B(t)$$
$$\frac{dC(t)}{dt} = \alpha_1 A(t) + \alpha_2 B(t) + (\alpha_3 - \alpha_4 - \alpha_5 - \alpha_6) C(t)$$
$$\frac{dD(t)}{dt} = \alpha_4 C(t) - (\alpha_7 + \alpha_8) D(t)$$
$$\frac{dE(t)}{dt} = \alpha_5 C(t) - \alpha_9 E(t)$$
$$\frac{dF(t)}{dt} = \alpha_6 C(t) - \alpha_{10} F(t)$$
$$\frac{dG(t)}{dt} = \alpha_7 D(t) - \alpha_3 G(t)$$
$$\frac{dH(t)}{dt} = \alpha_8 D(t)$$
$$\frac{dI(t)}{dt} = \alpha_{10} F(t) - \alpha_{11} I(t) \quad (4.6)$$

Where, $A(t) \sim I(t)$ is ratio of each state to total water volume, which change over time. α_i is the parameter (shown in appendix) of each change of states. Through data from each year in a region, we could get the parameter of each change of states by computer fitting based on our equations.

Then, we can predict the water situation in the next few years.

4.5. Type of Water Scarcity

In the world, the degree of water scarcity is divided into four types: resource type, engineering type, water quality type and comprehensive type [8]. Combining the method of partitioning, we determine to divide the type of water scarcity into four types according to the actual water situation in a region: Physical scarcity, Economic scarcity and Consuming or polluting scarcity.

Where, physical scarcity is where there is inadequate water in a region to meet demand. Economic is where water exists but poor management and lack of infrastructure limits the availability of clean water. Consuming scarcity is where increasing rates of personal consumption, or increasing rates of industrial consumption, or increasing pollution which depletes the supply of fresh water. According to the relevant literature [6], we determine to take utilization ratio of water resources λ_1 and per capita water supply λ_2 as basis of classification.

Based on the literature [6], considering the actual situation of water in Jiangsu, we think when $\lambda_1 \geq 80\%$, $\lambda_2 < 1700$, the type of water scarcity is physical scarcity. The type of water scarcity is economic scarcity, when $\lambda_1 \leq 80\%$, $\lambda_2 \leq 1700$. When $\lambda_1 \leq 80\%$, $\lambda_2 > 1700$, the type of water scarcity is consuming or polluting scarcity. This can be displayed in 2D drawings.

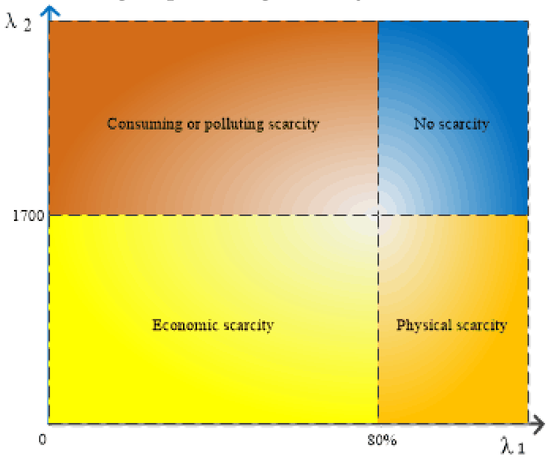

Figure 2: The type of water scarcity

5. Water Scarcity in Jiangsu

5.1. Why We Select Jiangsu

At first, we maintain that it is more practical to study a certain area than to study a country, so we choose a region. And we can see from the UN water scarcity map that Jiangsu is a water scarcity area. On the one hand, we find there are some areas in Jiangsu is not water scarcity, so the water scarcity area displayed on the map has a certain fuzziness. We determine to study the situation of Jiangsu carefully. On the other hand, Jiangsu is close to the sea, which is well developed maritime and air transportation, and the rainfall is abundant. It is convenient for us to design an intervention plan to improve the situation of water scarcity.

5.2. Measure The Water Situation

5.2.1. Application

According to the situation of Jiangsu Province, we chose the following indicators based on the principle of Evaluation Index. Besides, we judge the function of the index to the water scarcity, and all this has been shown in appendix. Using our evaluation model we can get the score of evaluation.

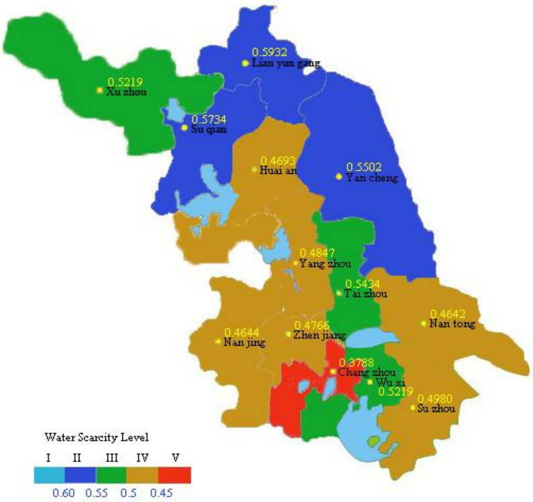

Figure 3: The score of evaluation

According to the classification criteria proposed by Falknmark Malin [8], we divide the situation into five types:

Table 3: The level of water scarcity

Types	Score
Over-exploited (Ⅴ)	＜0.45
Heavily exploited (Ⅳ)	0.45~0.50
Moderately exploited (III)	0.51~0.55
Slightly exploited (Ⅱ)	0.56~0.60
No-exploited (Ⅰ)	＞0.60

According to utilization ratio of water resources and per capita water supply in different areas of Jiangsu. Then we can get the situation of water scarcity in different regions of Jiangsu.

Table 4: The situation of water scarcity in different regions

City	The level of water scarcity	The type of water scarcity
Nankin	Heavily exploited (Ⅳ)	physical scarcity
Wuxi	Moderately exploited (III)	physical scarcity
Xuzhou	Moderately exploited (III)	economic scarcity
Changzhou	Over-exploited (Ⅴ)	physical scarcity
Suzhou	Heavily exploited (Ⅳ)	physical scarcity
Nantong	Heavily exploited (Ⅳ)	economic scarcity
Lianyungang	No-exploited (Ⅰ)	economic scarcity
Huaian	Heavily exploited (Ⅳ)	consuming scarcity
Yancheng	Slightly exploited (Ⅱ)	consuming scarcity
Yangzhou	Heavily exploited (Ⅳ)	physical scarcity
Zhenjiang	Heavily exploited (Ⅳ)	physical scarcity
Taizhou	Moderately exploited (III)	economic scarcity
Suqian	Slightly exploited (Ⅱ)	economic scarcity

5.2.2. Results and Sensitivity Analysis

Finally, we calculate the score of evaluation of the whole Jiangsu province using the total of province and get the score is equal to 0.49 and the type of water scarcity is physical scarcity. That is to say, Jiangsu is the region where water is heavily and the type is physical scarcity.

5.2.2.1. Model Testing

In order to test the validity of our results, we use AHP to test our model. We have drawn lessons from the judgment matrix provided by the literature [6], and consistency checking result (CR=0.1) indicated that the weighted coefficient is reasonable and efficient. The judgment matrix and consistency check has been shown in the appendix.

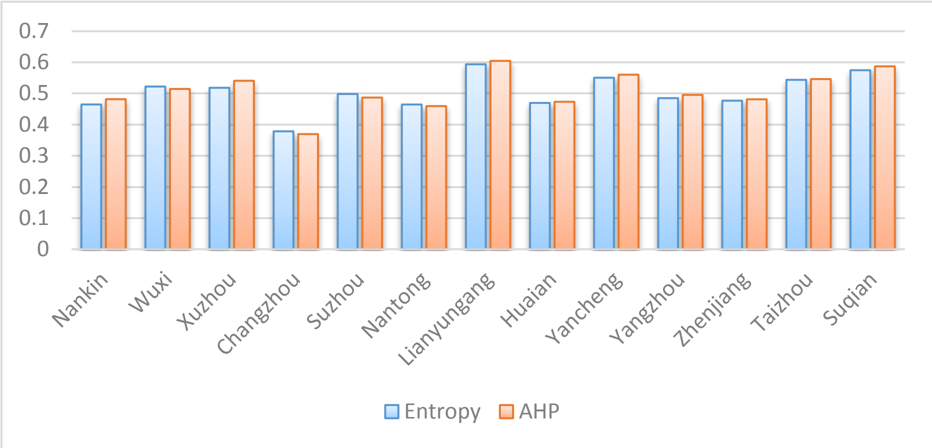

Figure 4: The comparison of results

Then, we calculate the weight of indicators by AHP and get the score of evaluation. From the figure 3 we find the results calculated by the two methods are very similar. So we have reason to believe that the result is credible.

5.2.2.2. Coordination of Usage of Water

We come up with the concept of coordination to measure the utilization of water resources. Because there are three primary causes for water scarcity: physical scarcity, economic scarcity and consumption of water. So we maintain that it is not accurate to only use the water resource utilization rate to measure the use of water resources. Therefore, we define Coordination Coefficient using the Coefficient of variation (CV) of utilization of water resources, it can define:

$$C_i = 1 - CV_i \tag{5.1}$$

Where, CV_i represents the coefficient of variation of simple i, it can be obtain from economics.

$$CV = (SD \div MN) \times 100\% \tag{5.2}$$

And SD is the standard deviation from which five-categories we selected, MN is the average value from which five-categories (It is shown in appendix)we selected. The coefficient range from zero to one, when the score is close to one, it means that the utilization of water resource better.

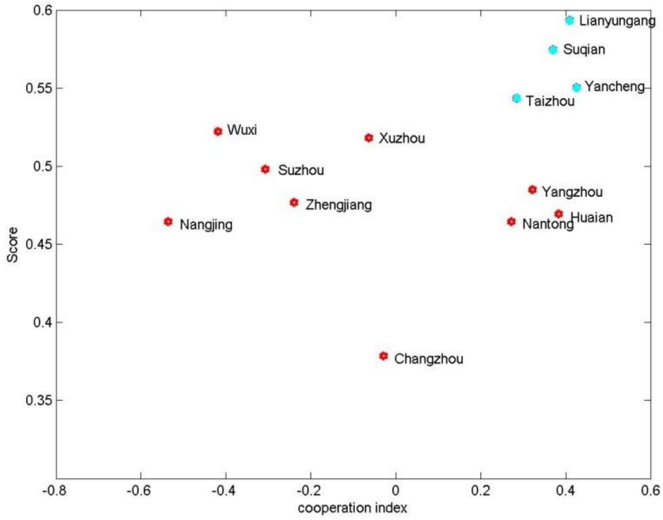

Figure 5: Cooperation Coefficient and the score of evaluation in a region

Cooperation coefficient can reflect the situation of the use of water resources, we can find four areas (Lianyungang, Suqian, Yancheng and Taizhou) with better water resources have a relatively high coordination coefficient. It means that these areas not only have better water resources than other regions, but also the use of water resources is very resaonable. If we want to improve the situation of water resources in a region, it is important to optimize the use of water resources.

On the other hand, in other areas where water is heavily, some areas have higher coordination coefficient. We think that if these areas want to improve water resources, it is not a excellent way to optimize the use of water resources. For these areas, we should adopt the method of external intervention to increase the local water resources. The rest of regions can take the above two methods to ease the water scarcity.

Therefore we divide these thirteen cities into three categories. The first kind consist of Lianyungang, Suqian, Yancheng and Taizhou, which have better water resources and don't need an intervention plan. The second kind consist of Yangzhou, Huaian and Nantong, which have a better coordination coefficient, so we need to design a plan to increase the local water resources such as desalinization plants. The third kind consist of the rest of regions, these regions not only need to increase the water resources but also need to optimize the use of water resources.

5.2.2.3. Sensitivity Analysis

In order to study the sensitivity of our model, we calculate the weight of the second layer index according to the the weight of third layer index which have been calculated by our model. Then, we can get the score of evaluation just using these second layer index. We want to study the sensitivity of these indicators to the model.

We take artificial interference to these indicators range from 1% to 5%, according to our model, we calculate the change of scores as follows.

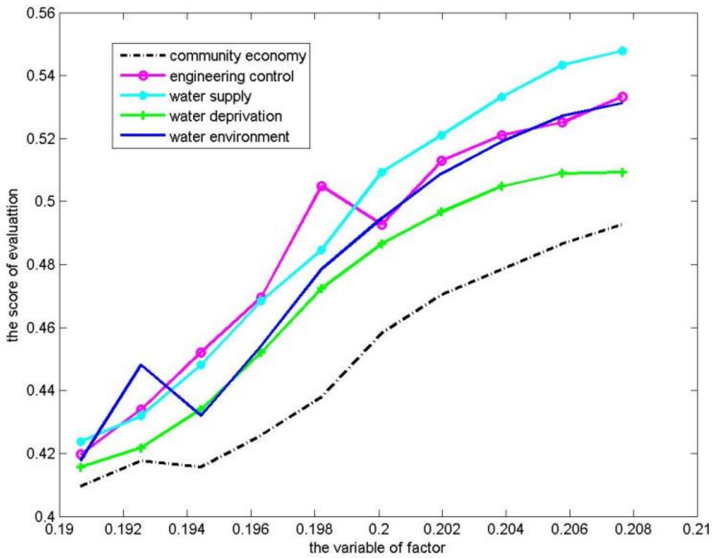

Figure 6: The sensitivity of indicators

From the figure we can find that if we change community economy, it will causes less changes of score compared to other indicators. When we change the water environment, the score has a larger change in the early stage, but gradually decreased. So, in general, we think the rate of change of water environment is less than water supply and engineering control. We can measure the rate of change by the slope of the curve, so we get the rank of sensitivity is

Water supply > Engineering control > Water environment > Water consumption > Community economy

We can conclude that if we want to improve the situation of water in a region, the best way is to increase water supply, then is to promote engineering control and improve water environment. To improve community economy will have a slower return. It is easy to understand that if we improve community economy, we will certainly increase the demand of water, this will have a negative effect on improving the situation of water.

5.2.3. Strengths and Weaknesses

Our model provides a measure of the ability of a region to provide clean water to meet the needs of its population, which can be applied in many countries or regions. We use the entropy weight method to calculate the weight of the index. It can make full use of information and avoid the subjectivity of determining weights. Besides, we can also believe that the results are credible. What's more, our model not only gives the level of water scarcity in a region but also gives the type of water scarcity, it is very accurate and useful for evaluating the situation of water in a region. The definition of coordination coefficient provides a good selection criterion for the following intervention plan.

Regarding weaknesses, because we grade the water scarcity needing to consider the actual situation of water in a region and draw lessons from relevant literature, this makes the level of a certain subjectivity.

5.3. The Water Situation in Next 15 Years

5.3.1. Predict The Water Situation

At first, we have collected the data from 2008 to 2014 about Jiangsu on the Internet. The method of least squares is a standard approach in regression analysis to the approximate solution of overdetermined systems, i.e., sets of equations in which there are more equations than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation. We achieve the ratio of nine kinds of water resources at first, and set parameters needed to fit. Based on the method of least squares, sum of squares of residues can reflect the results we get is good or bad. If the sum of squares of residues is very small, it means that the two sets of data are very close and the parameter fitted is believable.

$$\begin{cases} S=\sum_{i=1}^{n} r_i^2 \\ r_i = y_i - f(x_i,\beta) \end{cases} \tag{5.3}$$

Where, S represents the sum of squares of residues, the smaller the value, the better fitting. Setting the initial numerical value of (from 4.6)

Table 5: The initial numerical value

α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.01	0.01	0.01

A_0	B_0	C_0	D_0	E_0	F_0	G_0	H_0	I_0
0.1107	0.1894	0.21	0.12	0.0998	0.2857	0.009	0.0067	0.011

We can get

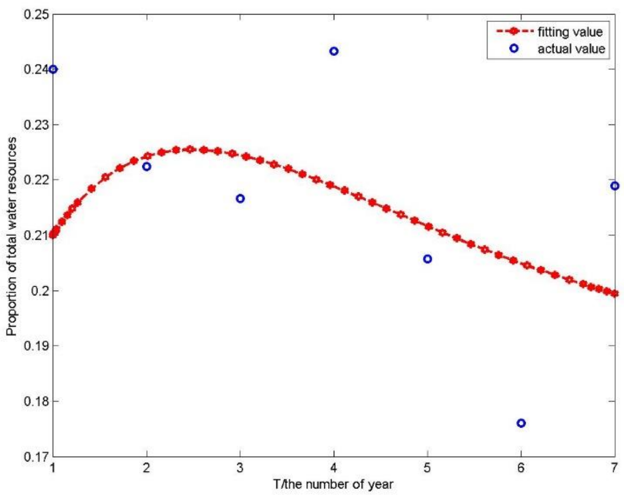

Figure 7: The fitting of water supply

Where, the parameters after fitting are

Table 6: The end value of parameters

α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}
0.28	0.35	0.21	0.12	0.1	0.13	0.2	0.21	0.2	0.18	0.18

The sum of squares of residues is equal to $S = 5.12 \times 10^{-6}$, which is very small, so the parameter we obtained is believable.

Then, we can fit the water supply for the next 15 years by using computer based on our dynamic model.

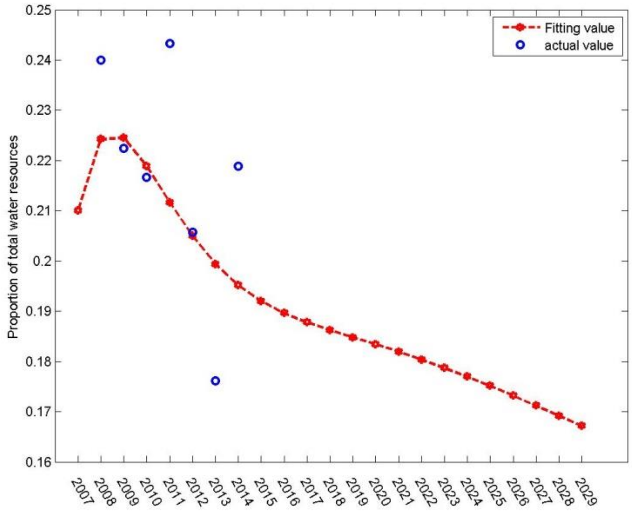

Figure 8: The water situation will be in next 15 years

Where, the vertical coordinate represents the ratio of the water supply in the total water, the horizontal coordinate indicates years. From the figure we can find that water supply is declining year by year and per capita water supply is equal to $443.7m^3$ in 2014, but per capita water supply only have $386.3m^3$ in 2029.

5.3.2. Effect on The Lives

According to our dynamic model, we can also get the changes of industrial water, agricultural water and water for life over time

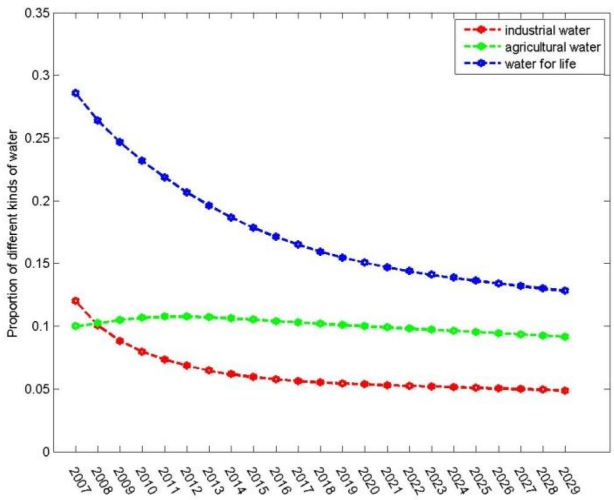

Figure 9: The change of Industrial, domestic and agricultural water

We can find that industrial water and domestic water will be limited, and decline with the increase of time. In 2014, the industrial water has $105.3\times10^8 m^3$ and the domestic water has $316.4\times10^8 m^3$. However, up to 2029, the industrial water have dropped down to $86.4\times10^8 m^3$ and the domestic water have dropped down to $227.3\times10^8 m^3$. Besides, agricultural water remains unchanged. Because the water supply decreased gradually as time goes on, it will definitely limit industrial water and domestic water. But as to agricultural water, in order to meet the demands of the population, it can't be cut.

5.3.3. Stability Analysis

We test the stability of the model by changing the initial value of the least square method.

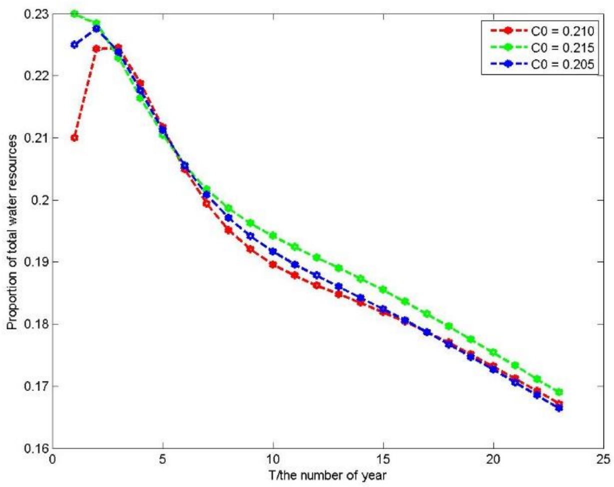

Figure 10: The water situations will be in next 15 years in different initial value

From the picture we can find that when we adjust the initial value, the prediction of water supply has not changed a lot. It shows that our model is stable locally.

5.3.4. Strengths and Weaknesses

Our model is based on the analysis of the intrinsic mechanism of the water cycle to predict the change of water supply in the future. This method is more effective than the static method to fit the data according to the time. At the same time, our model could accurately give the result of the time variation of each cycle system. Through the analysis of the results, we find that the change regulation is in accordance with the reality.

Regarding weaknesses, because we ignore the other sources of water supply and it may lead to a certain deviation of the results. The results of the prediction may be getting worse and worse as time goes on, so we need to constantly adjust the prediction according to the actual value.

6. Effection of Climate

We have known that climate change has a certain effect on industrial water, agricultural water and domestic water [1]. Climate mainly includes temperature, rainfall, light, natural disasters, etc. Compared to the temperature and rainfall, the impact of the light is difficult to quantify, so generally do not consider the impact of light. Natural disaster are accidental events, once it will have a huge impact on water consumption, we found in recent years, through consulting some information, the Jiangsu province has not occurred a bigger natural disasters. Therefore we don't consider the impact of natural disasters. Because of the correlation between rainfall and temperature, we only need to study one of them. With global warming, the influence of temperature on water consumption is increasing, so we use the temperature as our research object.

- The change of agricultural water demand

For the change of agricultural water demand, we just need to study the change of crop water requirement. We can calculate the crop requirement by Penman-Monteith formula recommended by the FAO, but we need to set up observation points to get the results. We find that Jiangsu is mainly grown in rice and wheat, in order to make quantitative calculation in our model, we assume that the growth date of crop is proportionate to the crop water requirement. Through consulting literature, the growth period of rice and wheat is usually 140 days, temperature rise at one degree, the growth period is shortened by 7 days [10] . Then, we can calculate that temperature rise at one degree, agricultural water demand decreased by 5%.

- The change of industrial water demand

The increase of temperature leads to the decrease of the efficiency of industrial cooling water, it makes industrial water demand increase. By fitting the industrial water consumption and annual average temperature in Jiangsu Province, we get temperature rise at one degree, industrial water demand increased by 2%.

- The change of domestic water.

The increase of temperature leads to the increase of domestic water. By fitting the domestic water consumption and annual average temperature in Jiangsu Province, we get temperature rise at one degree, per capita water consumption increased by 1.2L. It is very small relative to the total domestic water, so we don't consider the change of domestic water.

We find that the average temperature in Jiangsu province has increased by about one degree over the last 15 years. So we assume that the temperature will increase one degree in the next 15 years. Then, we can get the change of water supply in next 15 years considering climate.

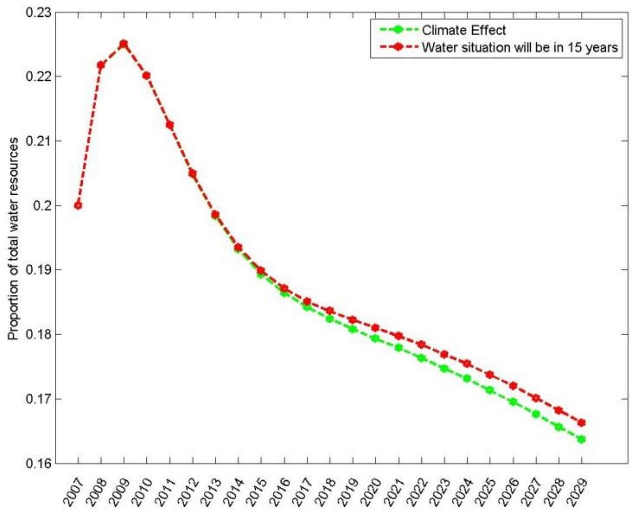

Figure 11: Climate effect

From the figure we can conclude that the water scarcity problem becoming exacerbated with climate change. And we can calculate the impact is about 0.9%.

7. Intervention Plan

7.1. Question analysis

By analyzing the dynamic model, we think the plan could be divided into two categories which consists of internal regulation and external intervention, so we come up with six solutions according to the actual situation.

Internal regulation:

- Scheme 1: Increase investment in water infrastructure.
- Scheme 2: Reduce industrial pollution (regulating the proportion of two stage sewage and primary sewage in industrial sewage).
- Scheme 3: Raise the utilization rate of water, for example: regulating water price, upgrading water related equipment.
- Scheme 4: Promote technological progress which can reducing the relative growth rate of industrial water and agricultural water.
- Scheme 5: Restrain population growth (reducing the relative growth rate of domestic water).

External intervention:

- Because Jiangsu is close to sea, so we think it is a good way to solve water scarcity by using desalinization plants and water harvesting.

7.2. Implementation and Simulation

In order to compare the quality of each program, we assume that the specific adjustment range for each program is about 5%.

For scheme 1: Increasing the investment of water conservancy facilities will lead to the increase of the acquisition rate of ground water and surface water, so we Increase the proportion of groundwater and surface water for the original 105%.

For scheme 2: Take measures to change the proportion of two sewage increased to 5% of the original, the proportion of primary sewage reduced to 5% of the original

For scheme 3: Increasing the utilization rate of water can reduce the waste of water resources, which is equivalent to reducing the output of water resources in the system, so reducing industrial water, agricultural water, and domestic water for 5%.

For scheme 4 and 5: Technical innovation of aquaculture will relatively reduce industrial water demand, so we change the industrial water into 95% of the original data. Reducing the excessive growth of the population can reduce the growth of domestic water consumption, so we adjust the water for the entire life of the original 95%.

Then we need to adjust the size of the other parts reasonably according to the principle of the equilibrium of the dynamical system (the proportion of each component is 1), and seek out the total proportion of the total water resources for the prognosis at last. We can get

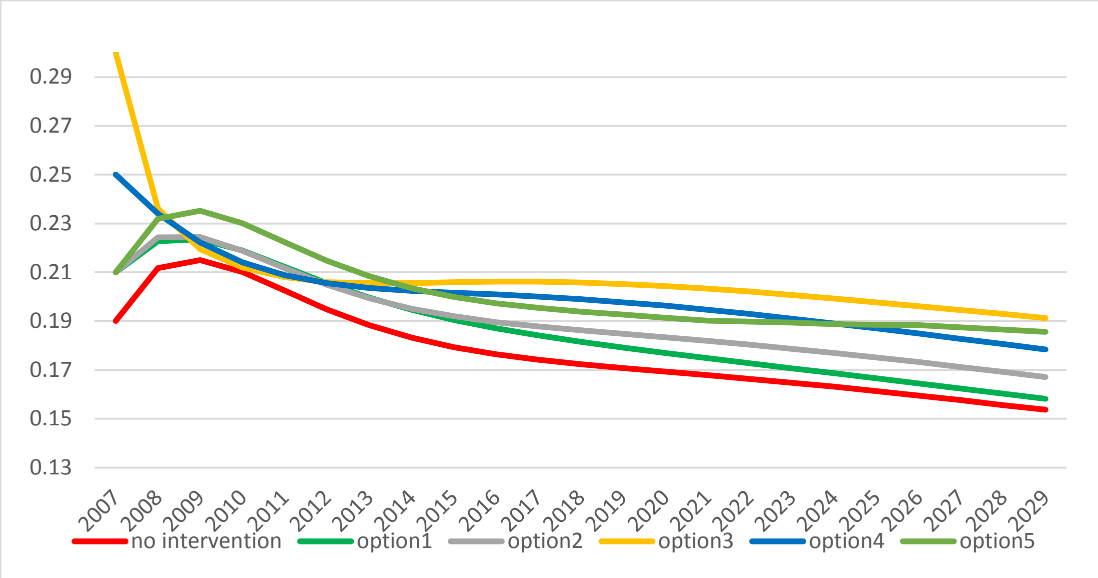

Figure 12: The result of plan

From the figure we can find that the change of each plan will lead to the increase of the total amount of water resources in the system, which shows that each solution all has a positive effect on the mitigation of water shortage. When refer to the effect of plan, we can obtain the rank is

Scheme 3 > Scheme 5 > Scheme 4 > Scheme 2 > Scheme 1

We add a new module to the dynamics model, which include desalination of sea water and Rainwater collection called “J”, they will improve the entire water ecosystem. The increase of the differential equations is

$$\begin{aligned} \frac{dC(t)}{dt} &= \alpha_1 A(t) + \alpha_2 B(t) + \alpha_{12} J(t) + (\alpha_3 - \alpha_4 - \alpha_5 - \alpha_6) C(t) \\ \frac{dJ(t)}{dt} &= -\alpha_{12} J(t) \end{aligned} \tag{7.1}$$

The figure has been shown in appendix.

7.3. Project Water Availability by Investment

7.3.1. Model

We plan to build an investment model based on investment funds and returns for water availability. It is a goal for investors to maximize the benefits, we believe that it can improve the situation of water in a region. At first, we define the following variables.

The variables and constants used in this paper are listed in **Table 7.**

Table 7: Notions

Symbols	Definition
m_j	For indicator j, invest-effective from a unit investment ($j=1,2\ldots19$);
x_j	For indicator j, the number of units which investors invest;
w_j	The weight of indicator j, it is constant;
f_{ij}	Evaluation of estimate of the i-th year and the j-th indicator;

f'_{ij}	Evaluation of estimate of the *i-th* year and the *j-th* indicator considering investment;
s_i	Score of the *i-th* year;
s'_i	Score of the *i-th* year considering investment;
I_1	The growth rate of evaluation of estimate;
I_2	The growth rate of Score ;
$f(\alpha_1, \alpha_2, ..., \alpha_n)$	Influence function of invest-effective based on the investment environment;
β	The coefficient of investment;

According to Investment and Profit, we can get the objective function is

$$\begin{cases} \max Z_1 = \sum_{j=1}^{19} x_j \times m_j \times w_j \\ \min Z_2 = \sum_{j=1}^{19} x_j \end{cases} \tag{7.2}$$

Where Z_1 and Z_2 are the object variable, we think it is very difficult to carry out a long-term plan at once, so we divide the 15-year plan into three parts consist of five years. We call it the three five-years-plan. Then we can get the first five-years-plan and it must meet the following conditions:

$$\text{s.t.} \begin{cases} \dfrac{f'_{aj} - f_{bj}}{f_{bj}} \geq I_1 \\ \dfrac{s'_{aj} - s_{bj}}{s_{aj}} \geq I_2 \\ f'_{aj} = f_{bj} + x_j \times m_j \\ s'_a = \sum_{j=1}^{19} f'_{aj} \times w_j \\ m_j = f(\alpha_1, \alpha_2, ..., \alpha_n) \\ a = b + 4 \end{cases} \tag{7.3}$$

Where b is the initial year we invest, a is four years later, the first formula represents mercantile rate of return must be greater than I_1, which we want to achieve. The second formula represents the rate of score must be greater than I_2, which we want to achieve. And the next five-years-plan could be set up based on the same equation.

7.3.2. Simulation

Because the value of m_j depends on the investment environment. Normally, it need to determined according to the preliminary investigation. So we decide to simulate the value by computer to draw up a plan. We hope that our score can be improved by 20% in fifteen years, so we devide the goal into three stages. In simulation, we transform multi-objective optimization into a single objective optimization i.e.

$$Max\ \ Z = \sum_{j=1}^{19} x_j \times m_j \times w_j - \beta \times \sum_{j=1}^{19} x_j \tag{7.4}$$

Where, Z is the object variable, then we get the 15-years plan based on our model by MATLAB as follows.

From the table we can get a detailed plan for fifteen years. At the same time

The first 5 year plan： a =2018, b =2014

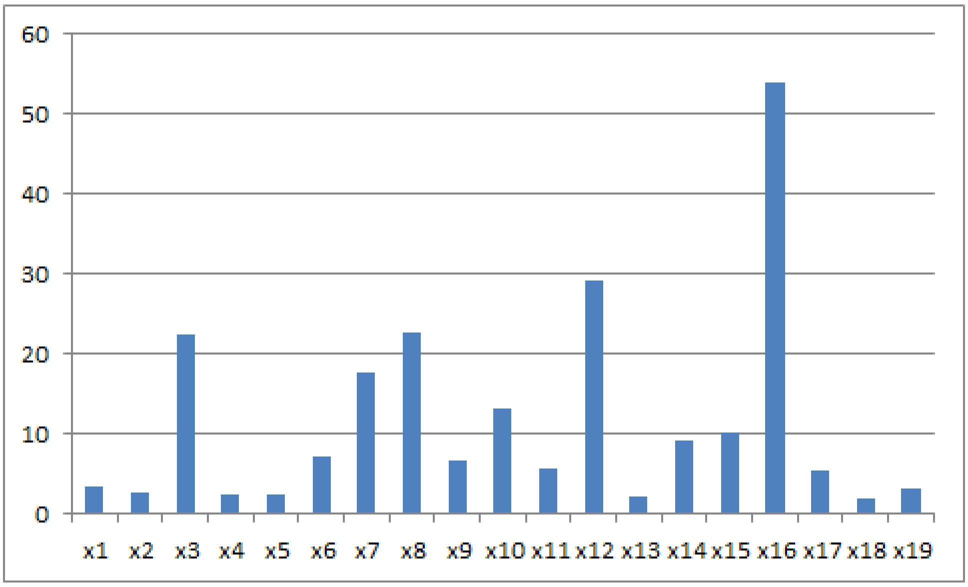

Figure 13: The number of units which investors invest

We can calculate $\Delta S = 0.022, S_{2018} = 0.512$

7.4. Results analysis

It has a positive effect on the entire water ecosystem, when we use desalinization plants and rainfall harvesting. And we assume that when the ratio of clean water in total water is under 0.15, water will become a critical issue. We can have a rough estimate of the time when this scarcity occur is that Scheme 1 is 2036, Scheme 2 is 2041, Scheme 3 is 2067, Scheme 4 is 2048 and Scheme 5 is 2057.

7.5. Strengths and weaknesses

In our model, we provide six schemes for improving the situation of water in a region from two categories, all these schemes can effectively alleviate the situation of water scarcity in a region. Then, we establish a multi-objective optimization model to find the best way to invest. Our model can be applied to many other fields.

Regarding to weakness, because the data is hard to collect, we use the computer to simulate the results. So the result has a certain uncertainty.

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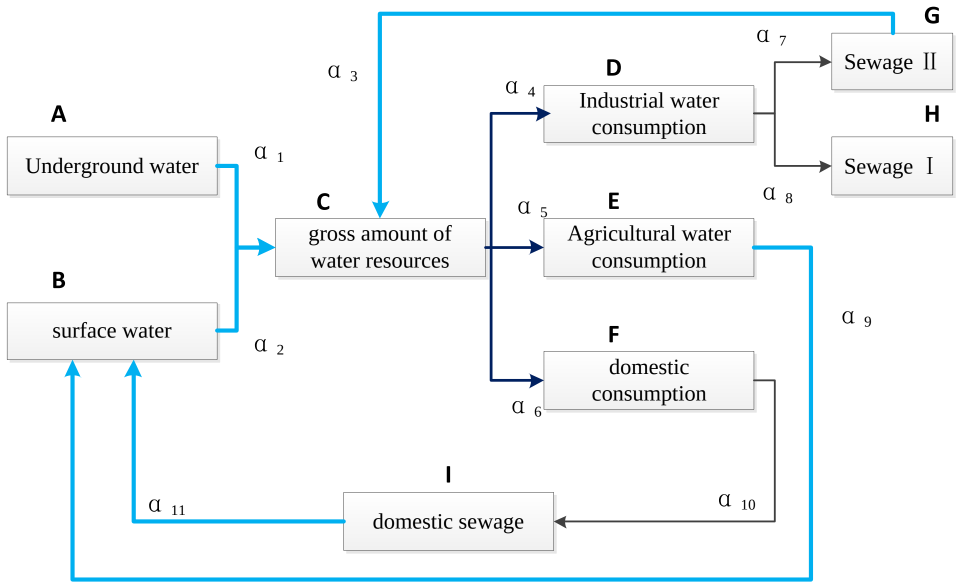
Appendix

classification	index	computational formula	character
community economy	density of population	number of population/area of land	N
	urbanization rate	urban population/number of population	N
	per person GDP	gross national product/number of population	P
	industrial output module	value of gross output/area of land	P
	unit water industrial production	value of gross output/total water resources	P
	unit water agricultural output	value of agricultural production/total water resources	P
	water resources of forestry output value	value of forestry production/total water resources	P
	unit of animal husbandry output value of water resources	value of stock farming production/total water resources	P
engineering control	the surface of the control	the amount of water into the reservoir engineering/surface water resources	P
	water utilization rate	water utilization rate	P
water supply	the modulus of water supply	output of supplying water/area of land	P
	per capita water supply	output of supplying water/number of population	P
	effective least irrigated farmland	effective irrigation area/agricultural acreage	P
water consumption	water consumption per GDP	water supply volume/GDP	N
	rural erosion rate	soil and water losses area/agricultural acreage	N
water environment	treatment rate of industrial effluents	industrial waste water processing/discharge amount of industrial waste water	P
	discharge standard-meeting rate of industrial wastewaters	amount of industrial wastewater emission standard/discharge amount of industrial waste water	P
	recycle rate of wastewater	industrial wastewater back to use/industrial waste water processing	P
	oxygen demand (cod) removal	oxygen demand industrial wastewater treatment/Industrial waste water processing	P



Water-cycling system

Table A: System comparison matrix

	community economy	engineering control	water supply	water consumption	water environment
community economy	1	1/2	1/3	1/4	1/5
engineering control	2	1	1/2	3	1/2
water supply	3	2	1	1/2	3
water consumption	4	1/3	2	1	2
water environment	5	2	1/3	1/2	1

Table B1: Comparative matrix of water supply

	the modulus of water supply	effective least irrigated farmland	per capita water supply
the modulus of water supply	1	2	3
effective least irrigated farmland	1/2	1	1/7
per capita water supply	1/3	7	1

Table B2: The comparison matrix of a water environment

	treatment rate of industrial effluents	discharge standard-meeting rate of industrial wastewaters	recycle rate of wastewater	oxygen demand (cod) removal
treatment rate of industrial effluents	1	2	1/3	2
discharge standard-meeting rate of industrial wastewaters	1/2	1	1/2	3
recycle rate of wastewater	3	2	1	2
oxygen demand (cod) removal	1/2	1/3	1/2	1

Table : RI-matrix

Vector matrix order（n）	1	2	3	4	5	6	7	8	9	10
RI	0	0	0. 58	0. 9	1. 12	1. 24	1. 32	1. 41	1. 45	1. 49