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Water Resources Supply and Demand Matching Model Based on Fuzzy Evaluation Method

Rui-Jie Tang[1], Xiao-Tong Liu[2], Fan-Ze Meng[3]

[1]Electric and Information College, Jinan University, Zhuhai, Guangdong, China
[2]International Business School, Jinan University, Zhuhai, Guangdong, China
[3]Humanities School, Jinan University, Zhuhai, Guangdong, China

Abstract
In order to reflect the degree of water shortage in an area, a model is built based on Fuzzy Analysis Method to quantify the matching degree of water supply and demand. It consists of two functions. One is supply function, including the fresh water storage, the sewage and the ecological water. And the other is demand function, including industrial water, agricultural water and domestic water. Then the Fuzzy Comprehensive Evaluation Method is employed to divide the matching degree into three levels. They are "Serious water shortages", "Moderate water shortages" and "Adequate water supply". In the end, the model was used in Hebei Province in China to judge its shortage degree and study the driving factors.
Keywords: *Water Resources, Supply-Demand Matching model, Evaluation, Fuzzy Comprehensive Evaluation*

1. Introduction

In the past century, water shortage is one of the most important problems in the world since the global population and economic grow fast. Water is widespread used in industry, agriculture and domestic life. Water use has been growing at twice the rate of population.

As the global water shortage problem is more and more serious, the scholars in related fields have carried out a series of studies on it. And they have achieved abundant research results. Variable-weight and Grey Correlation Model is proposed by Kang Yan to evaluate the water resources carrying capacity. Sanjiang plain, for example, demonstrates the feasibility of the model [1]; Fuzzy Comprehensive Model proposed by Xin-Guang Duan is for Xinjiang Province, China [2]; And Dynamic Measure Method proposed by Zheng Zang is for Liaoning Province [3]. Feng-Xia Li, and Jian-ping Guo summarize the research methods of water resource vulnerability. The DRASTIC index and GIS are mainly explained in their paper [4]. Li-Ping Zhang introduces the situation of water resources evaluation. There are seven single index systems to represent different aspects of water. Or several indicators form a comprehensive evaluation system [5]. Cai-Hong Hu, De-Di Liu and Bao-Zhao Yuan focus on the analysis of the demand factors and ignore the role of supply factors. It is not considered the balance between supply and demand [6-8].

Hereby, this article establishes a water resources supply and demand matching model from the perspective of the supply and demand of water resources. It can measure the water resources leveling of a district. At present, there is no unified standard internationally to judge the degree of water shortage. The per capita occupancy volume of water resources is used as a judge index in most case. According to the international standards, per capita volume of 2000 cubic meters of water resources is on the edge of acute water shortage, and 1000 cubic meters is the minimum requirement to maintain survival [9]. The vivacity of the index makes the concept of water shortage easier to understand. But water resources system is a complex system. There are many influencing factors for water shortage, including water resource waste, pollution and so on. But per occupancy capita volume cannot reflect these drivers. The water resources supply and demand matching model not only can measure the water shortage situation, but also can analysis the factors of the conditions. It is helpful to puts forward the targeted intervention plans to ease the water shortage.

2. The Water Resources Supply and Demand Matching Model

In order to study the matching degree of supply and demand, the supply and demand of water resources is specified. Every part of the two sides is considered practicably.

2.1 Supply and Supply Function

Supply, "all available freshwater resources", i.e. the existing water saving. However, fresh water saving is reducing by the impact of human activities. For example, sewage will make parts of the fresh water cannot be used. What's more, the ecological water storage capacity can be reduced by ecological destruction. The available fresh water under the impact of human activities is "The Actual Supply".

"The Actual Supply" equals to the fresh water storage subtract the useless portion. The useless portion includes: (1) the sewage; (2) the portion caused by the destruction of ecology, because the ecological water storage capacity decrease.

The real fresh water supply is S, the fresh water storage is S_P, the ecological water storage capacity is S_b, the sewage is S_r. The relationship between them is

$$S = S_P - S_r + S_b \quad (1)$$

Introduced by Yi Chuixiang [10], water storage capacity is related to vegetation coverage and precipitation. The relationship between them is

$$S_b = \sigma P \quad (2)$$

where, σ is the vegetation coverage, P is the precipitation.

In reality, even with enough precipitation, ecological water storage capacity is limited and it has critical value. To simplify, assuming a region's precipitation can't reach the upper limit of ecological water storage capacity.

In a word, the real fresh water supply satisfies the following equation

$$S = S_P - S_r + \sigma P \quad (3)$$

2.2 Demand and Demand Function

Demand means the "all water used in production and living". Human demand for water resources mainly has three parts: the agricultural water, industrial water and domestic water. Respectively constructing the three functions with their factors, so that acquiring the total demand of fresh water.

2.2.1 Agricultural Water Demand

The irrigation water is the main part of the agricultural water and the non-irrigation water only occupies a small part [11]. Thus the agricultural water is divided into two parts of the irrigation water and the non-irrigation water. Assuming the total agricultural water demand is Q_A, the irrigation water demand is Q_F, the non-irrigation demand is Q_C. They satisfy the following equation

$$Q_A = Q_C + Q_F \quad (4)$$

The irrigation water demand is positively relative to the irrigation area. It is negatively to the annual precipitation. What's more, with more population, the irrigation area will be larger, because more people need means more food production. Therefore

$$Q_F = \beta_1 S_F - \beta_2 P + \beta_3 R \left(\beta_1, \beta_2, \beta_3 > 0\right) \quad (5)$$

where, S_F is the irrigation area, β_1 is the water consumes by per unit irrigation area, P is the annual precipitation, β_2 is the impact of precipitation to agricultural product, R is the population, β_3 is the impact of population to irrigational product.

The non-irrigation water demand is related to the non-irrigation area and population. The relationship between them is to the irrigation equation

$$Q_C = \gamma_1 S_C + \gamma_2 R \quad (6)$$

Where, S_C is the non-irrigation area, γ_1 is the water consumes by per unit non-irrigation area, R is the population, γ_2 is the impact of population to non-irrigational product.

In a word, the agricultural demand can be presented as following

$$Q_A = Q_C + Q_F = \beta_1 S_F - \beta_2 P + \beta_3 R + \gamma_1 S_C - \gamma_2 R \quad (7)$$

2.2.2 Industrial Water Demand

The water using in power generation is the main part in the industrial water demand [12]. Therefore the industrial water demand is divided into two parts of power generation demand and other industry demand.

The industrial water demand is Q_I, power generation demand is Q_E, other industrial demand is Q_O. The relationships between them are shown below

$$Q_I = Q_E + Q_O \quad (8)$$

Also, the water demanding in the hydro power and the thermal power contributes the majority demand in power generation water [13]. Thus the equation between them as follow

$$Q_E = \alpha_1 E_e + \alpha_2 E_t \quad (9)$$

where, E_e is the hydro power capacity, α_1 is the water demanded in producing one unit of hydro power; E_t is the thermal power capacity, α_2 is the water demanded in producing one unit of the thermal power.

As for other industries, the water demand is directly related to industrial output value. Thus an equation as below

$$Q_C = \alpha_3 I \quad (10)$$

where, I is the industrial output value, α_3 is the water demanded in producing per unit of industrial output.

2.2.3 Domestic Water Demand

The domestic water mainly related to the population. The equation of the two variables as below

$$Q_D = \xi R \quad (11)$$

where, R is the population, ξ is one unit of water demanded per person in a year.

In a word, the fresh water demand is the sum of industrial water, agricultural water and domestic water. And their relationship is shown below

$$Q = \alpha_1 E_e + \alpha_2 E_t + \alpha_3 I + \beta_1 S_F - \beta_2 P + \gamma_1 S_C + \gamma_2 R + \xi R \quad (12)$$

The coefficient of water demand can be attained by employing statistical regression method to process the collected data. The collected data includes the evaluated region's metrics of all those factors discussed above.

2.3 Matching the Supply and the Demand

It, the matching degree of supply and demand, is the matching degree of "The Actual Supply" and "all water used in production and living". The matching degree can be defined as the ratio of them. Also, in order to differentiate the severity of the water shortage, the model employ the Fuzzy Comprehensive Evaluation Method.

2.3.1 Model Relations

In previous paper, the supply function (3) and the demand function (12) is known. The ratio of the two functions can reflects every cubic meters of water demand for water supply. M is the index of matching degree. It is

$$M = \frac{S}{Q} \quad (13)$$

2.3.2 Relative Water Scarcity Index by Fuzzy Comprehensive Evaluation

Eq. (13) just gives the relation of the model, however, it can't determine the severity of water shortage. Thus M can be grade up on the Fuzzy Comprehensive Method.

To a place, the water shortage degree can be divided roughly into three levels. "Serious water shortages", i.e. $M < M_{down}$, "Moderate water shortages", i.e. $M > M_{up}$ and "Adequate water supply", i.e. $M_{down} \le M \le M_{up}$.

Because of the change of M in the interval of $[M_{down}, M_{up}]$, the partial large normal distribution is employed as subordinate function [14]

$$f(M) = 1 - e^{-(\frac{M-a}{b})^2}, M_{down} \le M \le M_{up} \quad (14)$$

3. Analysis of Examples

3.1 Model Parameters

Referring to the UN water scarcity map [15], Guangdong, Liaoning and Hebei in China are selected on behalf of the "Moderate water shortages", "Adequate water supply" and "Serious water shortages" in the map.

Data sources and related instructions are as follows: all kinds of generated energy data are taken from China Energy Statistics Yearbook 2015 [16], and other data from China Statistical Yearbook 2015 [17]. Where, the annual precipitation of the provincial capital city replaces that of the Province. And the quantity of sewage will not increase as it expands into clean water. Part of the data is in Table 1:

Table 1: Metrics of supply factors and demand factors from 3 typical districts

Region (Province)	Total Supply (billion m³)	Sewage (10 kilo-tons)	Vegetation coverage (%)	Annual precipitation (mm)	Agriculture Water (billion m³)	Industrial water (billion m³)	Domestic Water (billion m³)
Guangdong	171.84	1.81	51.26	2234	22.43	11.7	9.61
Liaoning	14.59	0.53	38.24	362.9	8.96	2.28	2.44
Hebei	10.62	0.16	23.41	294.8	13.92	2.45	2.41

Take the data into the model to calculate M. Guangdong is 3.9, Liaoning is 1.2, Hebei is 0.6.But in fact, $M < 1$, i.e. the supply is less than demand. It means that the region has been the "Severe water shortages". So, M_{up}=3.9, M_{down}=1. And then using the condition to calculate the parameters of the subordinate function. They are $f(1) = 0.1$ and $f(3.9) = 0.9$. The parameters are $a = 0.8821$and $b = 3.1515$. And the result of subordinate function is

$$f(M) = \begin{cases} 0.9, M = 3.9 \\ 1 - e^{-(\frac{x+0.8821}{3.1515})^2}, 1 \le M \le 3.9 \\ 0.1, M = 1 \end{cases} \quad (15)$$

The trend of $f(x)$ is demonstrated in Figure 1:

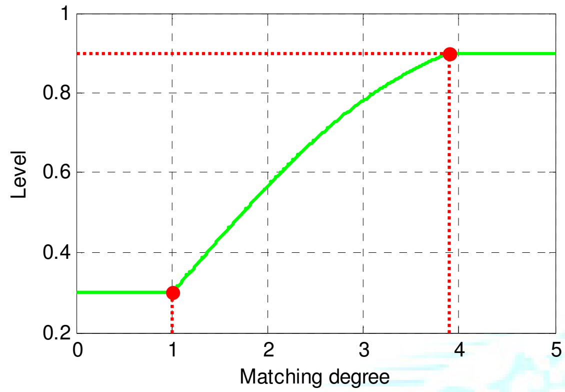

Figure 1: The trend of $f(x)$

3.2 Driving Factors of Water Shortage in Hebei Province

3.2.1 Regression of the Function

According to China Statistical Yearbook 2000-2013 [18], linear regression was made in distinct groups of data. These regression results are the parameters of supply function and demand function. Finally, Hebei's supply function and demand function are

$$S = S_P - S_r + \sigma P \quad (16)$$

$$Q = 1.8040E_e + 0.0004E_t + 0.0011I + 0.0454S_F - 0.0139P + 0.0011S_C + 0.0061R \quad (17)$$

Calculating and getting a new matching degree $M = 0.8048 < 1$, "Serious water shortages". It is the consistent with before. So, the factors above can be used to analyze the reasons of water shortage in Hebei Province.

3.2.2 The Demand Factors of Water Shortage in Hebei

According to the demand function, there are 6 factors influencing the changes in water demand: annual average precipitation, hydro power, thermal power, gross industrial output value, irrigation area, non-irrigation area, population. They are simulated to improve by 10%. Then calculating the ratio between each factor's variance and total water demand variance. The result is demonstrated in Figure 2:

In Figure 2, sorting every factor according to their variance ratios. Therefore calculating cumulative contribution rates by adding the variance ratios. Starts from the biggest factors irrigation area and the result is demonstrated in Table 2:

From Table 2, the cumulative contribution rate already reaches 95% by adding up the variance ratios of irrigation area, population and hydro power. This means these three factors contribute the main part of the change of demand. Thus concluding that irrigation water demand, population, hydro power water demand is the social drivers.

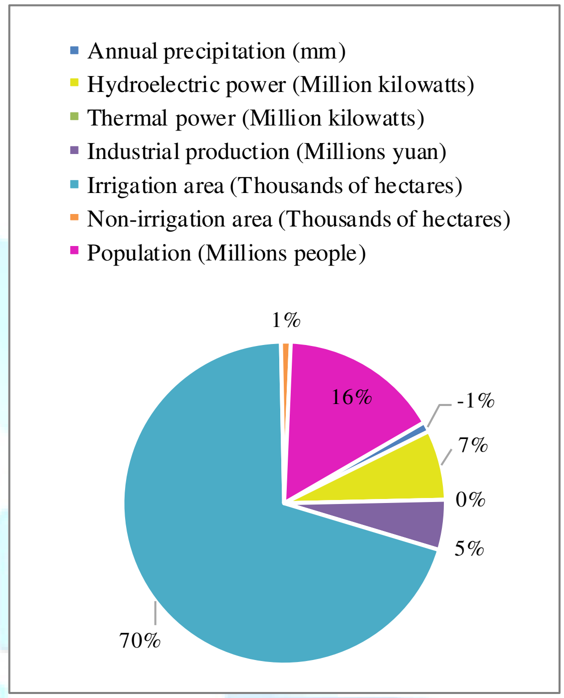

Figure 2 : Ratio between each factor's variance and total water demand variance

Table 2: Factors' cumulative contribution rates

Items	Irrigation area	Population	Hydro power
Cumulative contribution rates (%)	71.8%	87.9%	95. 0%

3.2.3 The Supply Factors of Water Shortage in Hebei

Stimulating all the factors to improve by 10%. Then getting the fresh water storage S_P = 106.2, sewage S_r = 0.161, ecological water storage capacity $\sigma P = 69.013$. From the result, the sewage only influence a little in Hebei's water supply. Its variance ratio is 0.15. And fresh water storage has the greatest influence to water supply. Its variance ratio is 0.99. From the supply perspective, the key driver of Hebei's physical scarcity is lack of fresh water storage compared to its water demand.

In a word, the environmental driver to Hebei's physical scarcity is lack of fresh water storage relative to its demand. The social driver to Hebei's shortage is large irrigation water demand, big population water demand and huge hydro power water demand.

4. Conclusions

In the situation of water shortage deterioration, it is important to find driving factors to carry out intervention programs. A supply and demand matching degree model is established in this paper. And Hebei Province is taken as an example. The shortage level in Hebei is given and explained its factors. Apart from the supply shortage, the irrigation water, population and hydroelectric power are also the main reason. It suggests that the model is practical and feasible.

However, there is something imperfect in the matching model. One is that some indicators are small and hard to quantify. They are ignored. And the other is the rating is rough, because of the fuzzy boundary of each level. If there are critical places of every level, a more accurate rating will be acquired.

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