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The water evaluation model and its application in China

Shujuan Yuan[1]*, Jingfei Chen[1], Aimin Yang[2], Qingpeng Ding[2], Xin Zhou[2]
[1]Qinggong College, Hebei United University, TangShan, (CHINA)
[2]College of Science, Hebei United University, TangShan, (CHINA)
E-mail: yuanshujuan1980@163.com; 43698059@qq.com

ABSTRACT

The fresh water in China occupies 6% of that of the whole world, while the population occupies 21.29% of that of the whole world. The shortage of the fresh water is a key factor limiting the development of China. According to the distribution of the water resources in the mainland China, with the aim of protecting the water resources, we give the priority to the earth surface water resource and regard it as the total amount of water resource to do the analysis and movement of the water.

Firstly, by consulting the data and combining the Chinese national conditions, we reckon the provinces with water shortage. Using the combination model of grey model and BP neural network, the water shortage in Year 2025 of the provinces with water deficiency can be predicted. The prediction relative error of the model is 0.31%. The prediction precision is high. The water resource strategy set according to the prediction value can satisfy the needs of the water resources in Year 2025.

Secondly, according to the different location of the provinces, the provinces with water shortage can be divided into inland areas and coastal areas. So we can get the best way of obtaining the water resources is to allocate. In the coastal areas, besides the movement of the water, we should consider the impacts of desalination to the economy, physics and the environment.

KEYWORDS

Earth surface water resource;
Analytic hierarchy process;
Water evaluation.

INTRODUCTION

Fresh water[1] is the limiting constraint for development in much of the world. Because of the factors, such as quick urbanization, pollution and drought, water shortage is a severe restraint of Chinese sustainable development. As a new technology industry, seawater desalination can provide another water resource to the human beings. The desalinated water, being a strategic water resource[2], can be promoted in the coastal cities, so that the social development and daily needs for water can be balanced, which plays a vital role in the safety of drinking water, even in the national security. At present the main industry of seawater desalination is located in the north of China, specifically Bohai Bay area.

INTRODUCTION OF EARTH SURFACE WATER RESOURCE

The gross of water resource[3] includes earth surface resource, underground water, and the duplication part of the earth surface water and underground water.

According to the water resource data of the Chinese provinces from China Statistical Yearbooks in the year of 2004 to 2012, we can get the average value M' of the per capita of total amount of water resource in each province and the average value N' of the per capita of the amount of earth surface water.

Define $i = \frac{M' - N'}{M'}$ is the contribution degree of the earth surface water to the total amount of the water resource. The fewer amount of i means the larger contribution degree of the water resource and the smaller contribution degree of the underground water resource. The values of M', N' and i in all the provinces can be shown in TABLE 1 and Figure 1.

From Figure 1 we can know the contribution degree of the earth surface water resource to the water resource total amount. The earth surface water resources of 26 provinces, such as Hainan, Guangdong, Guizhou, Sinkiang and other provinces, have larger contribution degrees to the water resource total amount; the earth surface water resources of the provinces, such as Hebei, Henan, Shaanxi, Ningxia and Inner Mongolia, have less contribution degree to the total amount of water resource.

Analysis from the aspects of water resource protection

(1) The significance of underground water resources

The natural underground reservoir constructed by the underground water resources can effectively reduce the evaporation[4]. It has some advantages of less investment, better efficiency of water storage, and low environment impact. It plays a very important role in control and restoration of the geological problems of the ecological environment and strategies storage and emergency water supply of the water resource.

(2) The contribution degree of earth surface water resource

According to the earth surface water resource amount in 1.1, the values of i of the provinces, such as Hainan, Guangdong, Guizhou and etc, are approaching to zero, which means that the water resources in the districts can be supplied by the earth surface water resources.

Considering the significance of the underground water resource and the contribution degree of the earth surface water resource, the related water amount is calculated by using the data of earth surface water resource.

TABLE 1 : The Values of M' (unit: hundred million m^3), N' (unit: hundred million) and i of the provinces

Province	M'	N'	i	Province	M'	N'	i
Shanxi	291.3	178.0	0.39	Hunan	2467.0	2456.2	0.00
Fujian	3065.7	3062.2	0.00	Hebei	202.8	77.2	0.62
Liaoning	711.3	624.4	0.12	Guangxi	3605.6	3605.6	0.00
Jilin	1444.1	1242.6	0.14	Hainan	4128.1	4081.4	0.01
Anhui	1182.3	1105.7	0.06	Sichuan	2924.1	2922.2	0.00
Jiangsu	562.0	436.5	0.22	Guizhou	2454.0	2454.0	0.00
Zhejiang	1756.7	1729.0	0.02	Yunnan	4188.0	4188.0	0.00
Guangdong	1846.4	1836.1	0.01	Tibet	1566027	156602.7	0.00
Inner Mongolia	1703.3	1185.9	0.30	Shaanxi	11508.0	1080.7	0.06
Shandong	937.0	836.2	0.11	Gansu	837.0	802.8	0.04
Jiangxi	3182.3	2552.7	0.20	Qinghai	128925	12542.3	0.03
Henan	470.7	344.3	0.27	Ningxia	160.3	122.9	0.23
Hubei	1659.4	1606.4	0.03	Sinkiang	4372.9	4134.6	0.05
Heilong jiang	1854.1	1522.9	0.18				

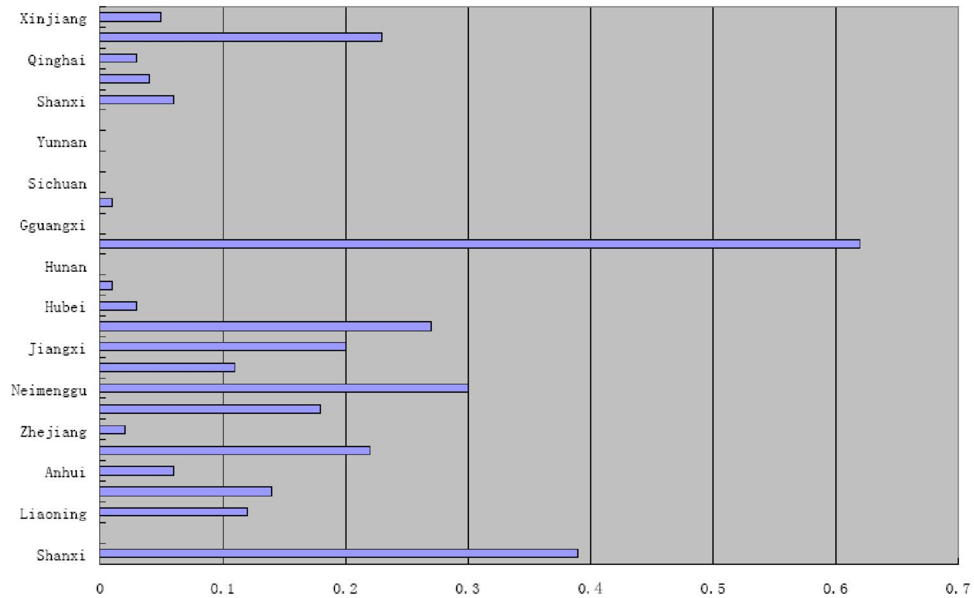

Figure 1 : The contribution degree of earth surface water of the provinces

THE EVALUATION OF QUANTITY VALUE OF PROVINCES WITH WATER DEFICIENCY

(1)Analysis of provinces with water deficiency

According to the international standards[5], if the per capita is less than 3000 m^3, the situation can be regarded as mild water shortage; if the per capita is less than 2000 m^3, the situation can be regarded as moderate water shortage; if the per capita is less than 1000 m^3, the situation can be regarded as the severe water shortage; if the per capita is less than 500 m^3, the situation can be regarded as extreme water shortage.

In the process of model preparation, we use per capita earth surface water resource amount to replace the per capita water resource amount from the aspect of protecting the water resource. Because of the large density of the population and less amount of per capita earth surface water resource, the provinces, whose per capita earth water resources are less than 1000 m^3, can be regarded as the place with water deficiency; the provinces, whose per capita earth surface water resources are between 1000 m^3 and 3000 m^3, can be regarded as the places with self sufficient water resource; the provinces, whose per capita earth surface water resources are more than 3000 m^3, can be regarded as the places with abundant water resources.

Then we can obtain the relation equation of resource amount of per capita earth surface water

$$\mathbf{N} = \frac{\mathbf{M}}{\mathbf{S}} \times \mathbf{T}$$

N is the per capita earth surface water resource amount; M is the per capita water resource amount; S is the total amount of water resource; and T is the total amount of the earth surface water resource.

From the above relation, the per capita earth surface water resource amount N of the Chinese provinces can be calculated. The provinces with water deficiency, self-sufficiency and sufficiency can be classified which can be shown in TABLE 2.

(2)Prediction of water shortage in year 2025

(a) Introduction of the prediction model

The data of the water resources in the provinces change a lot in years. If the simple model is used to predict the water amount in Year 2025, the prediction precision will not be accurate. So in this article, according to the water resource data of the provinces from 2004 to 2012, we use the combination model of grey model and BP neural network to predict. Firstly, we use grey model to predict the data and obtain one group of residual error values and then regard the residual error values as the input variables and the actual values of the predicted variables as the input variables

TABLE 2 : The water resource situation and per capita earth surface water resource amounts of provinces (m^3)

Province	N	Water Resource Situation	Province	N	Water Resource Situation
Beijing	49	Water Deficiency	Hubei	1606	Self-sufficiency
Tianjin	77	Water Deficiency	Hunan	2456	Self-sufficiency
Hebei	77	Water Deficiency	Guangdong	1836	Self-sufficiency
Shanxi	178	Water Deficiency	Guangxi	3605	Sufficiency
Inner Mongolia	1186	Self-sufficiency	Hainan	4081	Sufficiency
Liaoning	624	Water Deficiency	Chongqing	1806	Self-sufficiency
Jilin	1242	Self-sufficiency	Sichuan	3117	Sufficiency
Heilongjiang	1522	Self-sufficiency	Guizhou	2454	Self-sufficiency
Shanghai	136	Water Deficiency	Yunnan	4187	Sufficiency
Jiangsu	436	Water Deficiency	Tibet	156602	Sufficiency
Zhejiang	1729	Self-sufficiency	Shaanxi	1080	Self-sufficiency
Anhui	1105	Self-sufficiency	Gansu	802	Water Deficiency
Fujian	3062	Sufficiency	Qinghai	12542	Sufficiency
Shandong	836	Water Deficiency	Ningxia	122	Water Deficiency
Jiangxi	3017	Sufficiency	Sinkiang	4134	Sufficiency
Henan	344	Water Deficiency			

to establish a BP neural network model.

(b) Prediction of the provinces of water deficiency

We predict the water shortages of the provinces with water deficiency in years and the predicted average relative error is 0.31%, which means that we can get the higher prediction precision by using the combination model to predict the water shortage of the provinces with water deficiency in Year 2025. The prediction values of the water shortages of the provinces with water deficiency in Year 2025 can be found in TABLE 3.

(c) Prediction of provinces with water self-sufficiency

After predict the provinces with water self-sufficiency, we can get the average relative error of the prediction is 0.13%. The prediction result can be seen in TABLE 4. From the table, according to the --prediction of the provinces with water self-sufficiency[6], we can see the per capita earth surface water resources of Year 2025 are between 1000 m^3 and 3000 m^3, so the possibilities of transforming into the provinces with water deficiency in Year 2025 can be excluded. Therefore, these provinces will not be analyzed.

(d) Prediction of provinces with abundant water

According to the predicted value of surface water resource per capita in provinces of water sufficiency in TABLE 5 (the average relative error of predicted value is 0.09%), we can figure out each predicted value of

TABLE 3 : The prediction values of provinces with water deficiency in Year 2025 (unit: hundred million m^3)

Province	Water Shortage	Province	Water Shortage
Beijing	317.4084	Jiangsu	580.1741
Tianjin	204.1213	Shandong	882.2381
Hebei	719.8714	Henan	724.5612
Liaoning	316.7853	Gansu	62.67934
Shanxi	316.3567	Ningxia	68.73176
Shanghai	362.2249		

TABLE 4 : The Prediction value of per capita earth surface water resource of provinces with water self-sufficiency in Year 2025 (unit: hundred million m^3)

Province	Water Shortage	Province	Water Shortage
Inner Mongolia	2001.168	Hunan	2681.033
Jilin	1177.230	Guangdong	1470.544
Helongjiang	2670.860	Chongqing	2064.987
Zhejiang	1008.558	Guizhou	1745.494
Anhui	1774.085	Shaanxi	1295.009
Hubei	1479.410		

TABLE 5 : The predicted value of surface water resource per capita in provinces of water sufficiency in 2025 (unit: m^3)

Province	Water Shortage	Province	Water Shortage
Fujian	4037	Yunnan	4350
Jiangxi	3640	Tibet	176067
Guangxi	3600	Qinghai	8964
Hainan	3108	Sinkiang	4443
Sichuan	3005		

surface water resource per capita in provinces of water sufficiency in 2025 is still above 3000 m^3, therefore we can rule out the possibility for provinces of water sufficiency becoming provinces water self-sufficiency.

THE APPROACH FOR PROVINCES OF WATER DEFICIENCY GAINING WATER RESOURCE

According to the geographical distribution of China's land area, we divide China's land area into interior areas and coastal areas.

(1)The approach for provinces of water deficiency in interior areas gaining water resource

We set priority to take the surface water resource as allocating resource to supply the provinces of water deficiency. Therefore we can take the movement of water resource as the only approach for provinces of water deficiency in interior area gaining water resource.

(2)The approach for provinces of water deficiency in coastal areas gaining water resource

Considering the unique way for coastal areas gaining freshwater resource- de-salinization, combined movement with de-salinization, we decide to use AHP (analytic hierarchy process)[7] to form the hierarchical structure as the best freshwater supply approach for coastal areas as shown in TABLE 6.

To confirm the index weight of the best freshwater supply approach in coastal areas, we form the Analytic Hierarchy Figure as shown in Figure 2.

According to the analysis of the factors above in reference 9-12, we form some judgment matrixes between different layers for comparison.

Judgment matrix from A to B:

$$\mathbf{R}_{11} = \begin{bmatrix} 1 & 3 & 3 & 1 \\ 1/3 & 1 & 1 & 1/3 \\ 1/3 & 1 & 1 & 1/3 \\ 1 & 3 & 3 & 1 \end{bmatrix}$$

Judgment matrix from B to C:

$$\mathbf{R}_{21} = \begin{bmatrix} 1 & 5 \\ 1/5 & 1 \end{bmatrix}, \mathbf{R}_{22} = \begin{bmatrix} 1 & 3 \\ 1/3 & 1 \end{bmatrix}, R_{24} = \begin{bmatrix} 1 & 3 \\ 1/3 & 1 \end{bmatrix}$$

TABLE 6 : The best freshwater supply approach for coastal areas - the hierarchical structure

Destination layer A	Criterion layer B	Factor Layer C	Freshwater supply approach D
The best freshwater supply allocation for coastal areas	Economy B_1	Cost consumption C_1	Movement D_1
		Maintenance consumption C_2	Desalinization D_2
	Physics B_2	Hydrologic flow condition changes C_3	
		Geological changes C_4	
	Efficiency B_3	Efficiency C_5	
	Environment B_4	Social environment C_6	
		Natural environment C_7	

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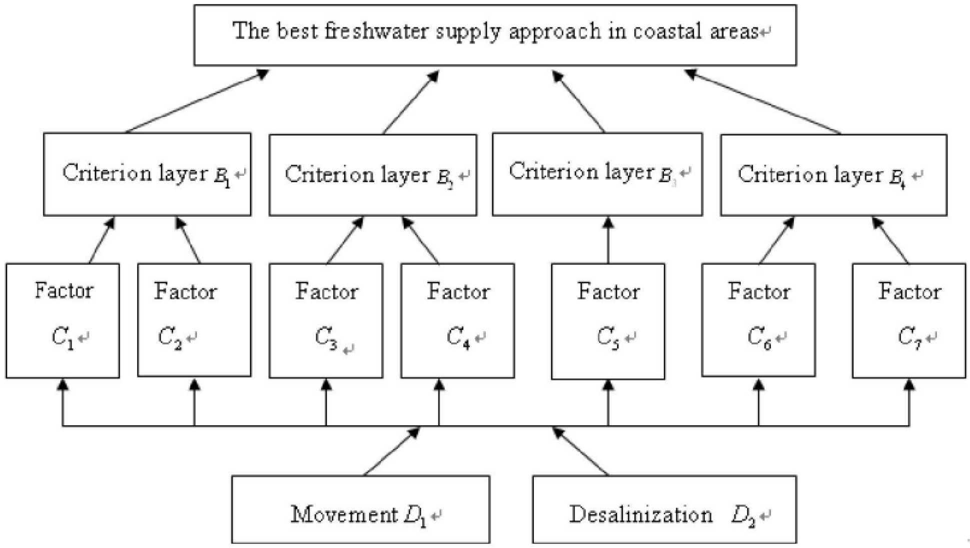

Figure 2 : The Analytic Hierarchy Figure of the best freshwater supply approach in coastal areas

Judgment matrix from C to D:

$$R_{31}=\begin{bmatrix}1 & 5\\ 1/5 & 1\end{bmatrix},\ R_{32}=\begin{bmatrix}1 & 3\\ 1/3 & 1\end{bmatrix},\ R_{33}=\begin{bmatrix}1 & 5\\ 1/5 & 1\end{bmatrix}$$

$$R_{34}=\begin{bmatrix}1 & 3\\ 1/3 & 1\end{bmatrix},\quad R_{35}=\begin{bmatrix}1 & 5\\ 1/5 & 1\end{bmatrix},\quad R_{36}=\begin{bmatrix}1 & 3\\ 1/3 & 1\end{bmatrix},$$

$$R_{37}=\begin{bmatrix}1 & 3\\ 1/3 & 1\end{bmatrix}$$

With the help of *Saaty's* method of weighting, we can calculate the index weight of each layer and finally figure out the different combinational weights by weighting: the weight value of movement $w_1 = 0.667$, the weight value of Desalinization $w_2 = 0.333$

CONCLUSION

The gross amount of water resource includes the amount of surface water resource, the amount of underground water resource and the repeated amount of surface water and underground water. If we allocate water resource basing on the gross amount of water resource, it is bound to over-explore the underground water resource in some regions that would cause the subsidence and even collapse of ground, saline intrusion, salinization of underground water, exhaustion of surface water, the and exsciccation of ground vegetations in arid and semi-arid regions, and deterioration of water quality. Consequently, from the point of protection of underground water, we should give priority to the use of surface water and take it as the gross amount of water resource during calculation.

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