The Analysis of the Clean Water Supply and Demand in the Water-Scarce Regions

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Abstract

Starting with the supply-and-demand analysis in the background of global water shortage, considering various influence factors from natural environment and society. By using the supply and demand balance theory dynamically. We construct the model of water resources supply and demand index to measure the ability of clean water supply in different regions. And take Qingdao as an example to verify the general principles of our model. Calculated that the balance index of water supply and demand is 0.48 while Qingdao's value is 0.69, which means Qingdao's water resources situation is very grimmer. In order to finding and solving problems, we designed an intervention plan to alleviate the water shortage and drew the conclusion that the intervention of rainwater collection technology every 1% increase will make the total increase in the supply of 0.0936 units. Besides, we made a qualitative analysis of the possible impacts of the intervention through forecast the water resources in the next 25 years, and found that there are two balance point of supply and demand system, water shortage situation eased, and there will be sufficient water supply to match demand by 2035.

Key Words: *Water Scarcity, Balance Model of Supply and Demand, Price Index, Intervention Plan.*

Introduction

Water is an essential material for the survival of human beings and all living things. It is a very valuable natural resource for industrial and agricultural production, economic development, power generation, water transport, tourism and environment improvement, etc. 70% of the earth is covered with water, it can be said that the world runs on water, so clean and reliable water supply is not only for the benefit of mankind, but also for the survival of mankind.

According to the United Nations, 1.6 billion people (one quarter of the world's population) experience water scarcity. Water use has been growing at twice the rate of population over the last century. 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. Many scientists see this water scarcity problem becoming exacerbated with climate change and population increase. The fact that water use is increasing at twice the rate of population suggests that there is another cause of scarcity – is it increasing rates of personal consumption, or increasing rates of industrial consumption, or increasing pollution which depletes the supply of fresh water, or what?[1]

Therefore, this study aims at analyzing what are the reasons for water scarcity, how to measure the supply and demand of water resources quantitatively, and how can we accurately predict future water availability.

Problem Statement and Analysis

In order to improve access to clean, fresh water, we divide the water-scarce problem into four small problems.

- Develop a model that provides a measure of the ability of a region to provide clean water to meet the needs of its population. Dynamic nature of the factors that affect both supply and demand need to be taken into account during modeling process.
- Pick one typical country where water is heavily overloaded. Explain why and how water is scarce in this region considering both the social and environmental drivers.
- Forecast what the water situation will be in 15 years of the chosen region. Discuss how this situation impact the lives of citizens of the region.
- Design an intervention plan taking all the drivers of water scarcity into account. Explain how the plan mitigate water scarcity. And project water availability into the future.[1]

Basic Assumption & Symbols Explanation

Basic Assumption

- The demand of water resources only to consider residential water, industrial water and agricultural water, because the proportion of the total water consumption of the ecological environment is very small, it is not to be consider here.
- Climate change will cause changes in rainfall, which will affect the surface water and groundwater. Because there is not much change in the climate of a region in the short term, we assume that the change in supply caused by climate change is negligible.

Symbols Explanation

Tab.1 Variables and their meanings

Number	Sign	Significance
1	D_i	The demand of water resources, i represents different aspects of water
2	S_i	The supply of water resources, i represents different sources of water resources
3	γ_{ij}	Environmental factors affecting water resources, i, j said different aspects
4	λ_{ij}	The social factors affecting water resources, i, j said different aspects
5	I	The capacity of areas to provide clean water
6	t	The time variable is used in the prediction model

[1] Interdisciplinary Contest In Modeling problem E :http://www.comap.com/undergraduate/contests/

Problem I Water Supply And Demand Evaluation Model

Problem Analysis

Combined with the idea flow chart (Fig.1), we divide the water shortage into physical shortage and economic shortage. Classified the factors that will affect the physical and economic shortage from two angles of social and environment. Then giving further analysis of how these factors affect the supply and demand of water resources. According to the balance relationship between the demand and supply of clean water resources, we define the supply and demand balance index to quantitatively analyze the ability of a region to provide clean water.

The water demands is divided into residential water, industrial water and agricultural water, water resources supply is divided into natural water, seawater desalination, rainwater collection, reclaimed water and water transfer. In addition, the population growth, technological progress, pollution and other environmental and social factors are added into the model as dynamic impact factors, to build a dynamic clean water supply-and-demand balance model. When the supply and demand index of a region is greater than the supply and demand balance index, indicating the lack of water resources in the region, that is, the ability to supply water resources is weak. On the contrary, it shows that the water supply capacity of the area is strong.

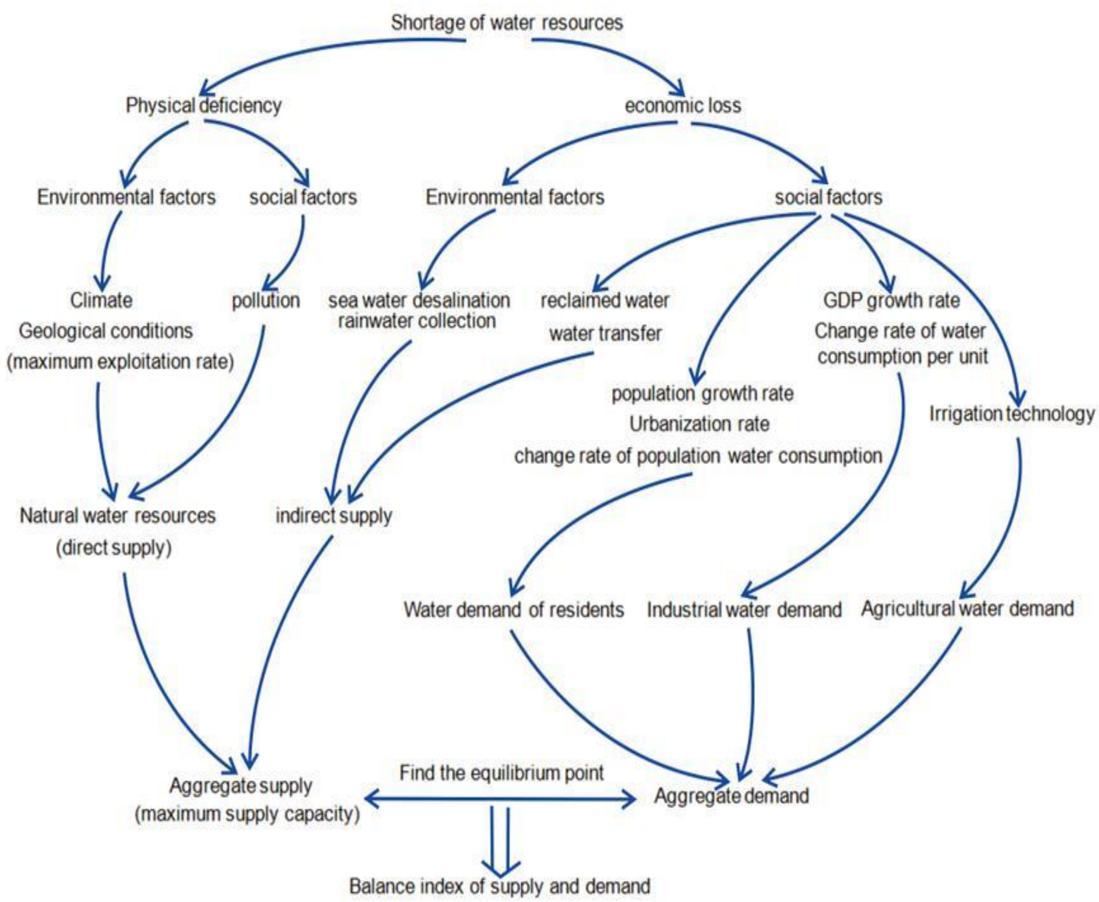

Fig.1 Idea flow chart

Model Preparation

Water Demand Subsystem

We divide the total water demand D into three parts: water demand of resident D_1(residents living water and urban public water), industrial water D_2 demand and agricultural water demand D_3. This is the composition of the total water demand from a static point of view, and the values can be directly obtained in a variety of statistical sites. However, taking into account the time factor, with the passage of time, the total water demand is also affected by the impact of population growth, technological progress, economic development and other environmental and social factors. These dynamic factors are further analyzed.

The dynamic impact factors of Water demand of residents D_1: population growth and improving living standards will increase the domestic water use, improving urbanization level will lead to the increase of urban public water. Therefore, both of them will lead to the increase of water demand of residents. We use the area's population growth rate λ_{11}, per capital water consumption growth rate λ_{12} and urbanization rate λ_{13} to measure this effect.

The dynamic impact factors of Industrial water requirement D_2: Consider factors affecting industrial water demand from two angles of the scale and efficiency of industrial water. The expansion of industrial scale will drive the increase of water demand in industrial production, and the expansion of industrial scale is usually consistent with the growth of GDP. Therefore, we use GDP growth rate $\lambda_{21}$to measure the amount of water needed for industry due to the expansion of the scale. At the same time, along with the advance of technology and progress in water-saving management, water use efficiency improved, water consumption of per unit of industrial added value showed a decreasing trend. We use the water consumption change rate of per unit of industrial added value $\lambda_{22}$to measure the change of industrial water demand caused by the increase of water use efficiency. Agricultural water demand D_3: The agricultural water demand is mainly used for agricultural irrigation. In recent years, the agricultural irrigation technology has reached rather mature stage because of the rapid development in the past few years, and the improved space is limited. So we regard agricultural irrigation technology as a fixed value. Besides, the agricultural land area is relatively fixed, therefore, we see the agricultural water demand remained unchanged as the average level in 2014.

Water Supply Subsystem

We define the maximum water supply capacity as an effective development and use of existing natural water resources (direct supply), and the ability to convert potential water resources into water (indirect supply).

Direct Supply

Direct supply is the freshwater resources that can be obtained directly from a region, mainly of it are natural water resources. Natural water resources S_1 include surface water and groundwater. Because of the fixed amount of natural water resources, its existence is mainly affected by the environmental factors: climate change γ_{11}, development potential, the maximum exploitation rat γ_{12}, and the pollution discharge coefficient γ_{13} of the social driving factor.

Indirect Supply

Indirect supply includes the desalination of sea water S_2, rainwater collection S_3, reclaimed water S_4 and water transfer S_5.

Seawater desalination refers to turn the sea water into useful water by desalinizing and other steps, thereby increasing the supply of water. At present, most countries have been able to use desalination technology maturely, the specific amount of water provided by the sea water can be found in the Statistics Bureau of the state, so we can quantify seawater desalination by specific values got in the Statistics Bureau or the product of seawater desalination technology index and seawater that is to be desalted.

Rainwater harvesting is refers to the use of rainwater harvesting technology to collect rainwater for agricultural irrigation, urban greening and so on, we use the product of rainfall and rainfall collection techniques to quantitatively measure the change amount of water supply caused by climate change.

Reclaimed water is a kind of water quality index, which can be used as a kind of beneficial use by the waste water or rain water after being treated properly. We use the product of the sewage discharge quantity and the sewage conversion coefficient to measure the change of the reclaimed water.

Water transfer refers to water transfer from an area to another area through infrastructure to meet the water demand. This part depends on the national policy and the level of infrastructure construction, it can be quantified by specific transfer water data from Department of Statistics.

The indirect supply mainly depends on the technological progress: seawater desalination capacity, rainwater harvesting technology, sewage treatment capacity and the level of infrastructure construction.

Model Establishing and Solving

In order to quantitatively measure the capacity of a region to provide clean water, we have a systematic analysis of the component of clean water from the eagle of demand and supply, and how the environmental and social driving factors of all kinds affect the water demand and supply.

For the demand, assuming this moment for $t = t_0$, when $t \leq t_0$, due to demand data has occurred, That is, at the moment the demand D_t is equivalent to the amount of known, for a fixed value which can be obtained from the Department of Statistics directly, the value already contains a variety of effect of driving factors. And when $t > t_0$, D_t equivalent to the prediction of water demand in future time. At this time the various driving factors play a role. Predict the future value of the driving factor λ_{ij}^t according to the past value, taking it as a factor coefficient to multiply the demand D_{it_0}, and then added the three part demand prediction values together, that is to get the final total demand D_t.

The analysis of the supply level is similar to the demand. The main idea is that all kinds of environmental and social factors have no influence on the occurrence water and occurring water supply, but just affect the supply of water resources in the future. Differ from the demand is that the supply of S_1 ,S_2 ,S_3, S_4, S_5 itself is not only the supply component but also the driving factor. In predicting the total supply of the future will also need to predict this part, so it is S_{it}rather thanS_{it_0}.

$$D_t = \begin{cases} D_{1t} + D_{2t} + D_{3t} & t \leq t_0 \\ \lambda_{11}^t * \lambda_{12}^t * D_{1t_0} + \lambda_{21}^t * \lambda_{22}^t * D_{2t_0} + D_{3t_0} & t > t_0 \end{cases}$$

$$S_t = \begin{cases} S_{1t} + S_{2t} + S_{3t} + S_{4t} + S_{5t} & t \leq t_0 \\ \gamma_{11}^t * \gamma_{12}^t * \gamma_{13}^t * S_{1t} + S_{2t} + S_{3t} + S_{4t} + S_{5t} & t > t_0 \end{cases}$$

Thus we can define clean water supply and demand index

$$I_t = \frac{D_t}{S_t}$$

This index I_t represents the ability of an area at the time t to provide clean water, but because the I_t here is just a ratio, cannot judge if the value represent oversupply or in short supply. Therefore, we need to find a balance point, at the point the maximum supply of clean water just right to meet the water demand, the ratio of demand and supply at this time is the supply-and-demand balance index I_0(due to the presence of the distribution of water resources uneven, the largest mining limit, the reason of low efficiency utilization of water resources, demand is not equal to the supply at the equilibrium point, general supply will be greater than demand, that is, $0 < I_0 < 1$), when $I_t > I_0$, indicating that the area is deficient in clean water, the ability to provide clean water is weak; when $I_t < I_0$ shows that the area is adequate for clean water, ability to provide clean water is strong.

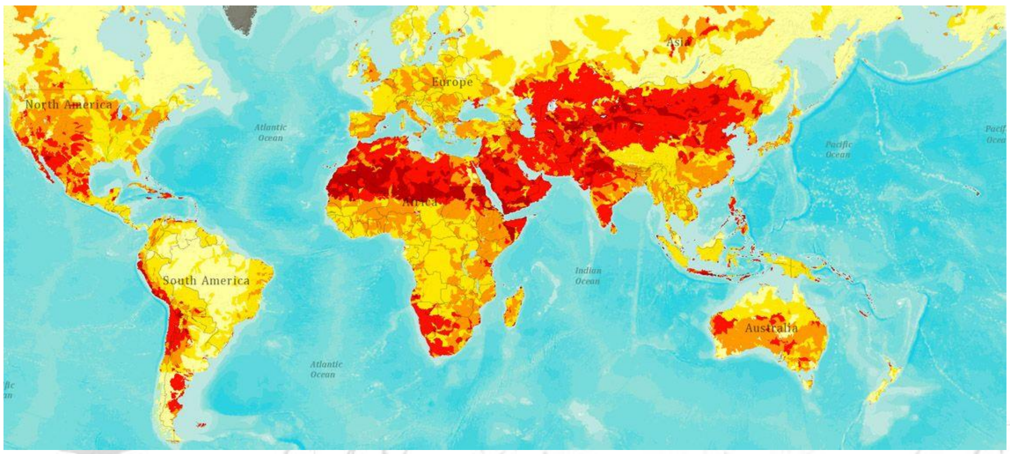

Fig.2 Global water scarcity map

In order to get the balance index of supply and demand, we intend to select a representative area of which water resources is relatively abundant as our research object, and the clean water supply and demand index of this area is used as the balance index of supply and demand. The index represents the general level of the balance of supply and demand of water resources, and can be used as a basis for the comparison of the index of supply and demand at any time.

According to the latest global water scarcity map provided by World Resources Institute, we find relatively abundant water resources in Sudan, South America, so we choose Sultan as a reference basis.

Tab.2 Clean water resources supply and demand data in Sultan in 2014

Total demand of clean water 10^9/ m^3			Total supply of clean water 10^9/ m^3				
Water demand of residents	Industrial water demand	Agricultural water demand	Natural water resources	Sea water desalination	Rainwater collection	reclaimed water	Water transfer
0.95	0.075	25.91	37.8	0	5.3	0.42	7.6
24.83			51.12				

Data source: United Nations Food and Agriculture Organization, FAO water resources

As a measure of the clean water supply capacity of Sultan in 2014, it is the time that has occurred, so we can take the data obtained from Department of Statistics into the formula (1), (2) of the first equation directly to get the balance index. Through the calculation we get $I_0 = 0.48$. Take the water supply and demand data along with the driving factors of the region to be tested into the model, we can calculate the supply and demand indexI_t of the region, then compare I_t with 0.48. If $I_t > 0.48$ indicate the region is lack of water supply and need to take relevant measures to improve the water supply capacity; On the contrary, it shows that there is sufficient water supply capacity of the region.

Problem II Water Shortage Area Analysis

Problem Analysis

Start with using the UN water scarcity map to pick one country or region where water is either heavily or moderately overloaded. Then according to the model we have established to explain the physical and economic conditions of the water resources in this area, which means to analyze what has caused the water scarcity from both social and environmental factors. Considering regional representation and typicality, we select Qingdao as the research object, to do subsequent research and verify our model.

Model Preparation

Qingdao city is located in the south of Shandong Peninsula, southeast of the city adjacent to the Yellow Sea, is a Coastal Hilly City. However, Qingdao is one of the serious water shortage cities in the north of China. On the one hand, the demand of water resources in Qingdao city is growing fast.; On the other hand, water resources available for further development is very limited, the degree of dependence on passenger water will continue to increase, local groundwater overdraft. The competition among urban water, industrial water and agricultural irrigation water is increasing. Therefore, the utilization and allocation of water resources in Qingdao will have a direct impact on the economic and social development.

Model Establishing and Solving

We first use task one model to calculate the net water supply capacity of Qingdao city.

$$D^* = D_1^* + D_2^* + D_3^*$$

$$\boldsymbol{S}^* = S_1^* + S_2^* + S_3^* + S_4^* + S_5^*$$

Among them,D^*, D_1^*, D_2^*, D_3^*, respect the total water demand, water demand, industrial water demand, agricultural water demand respectively; S^*, S_1^*, S_2^*, S_3^*, S_4^*, S_5^* respectively expressed the total supply of natural water resources, seawater desalination, rainwater collection, reclaimed water and water transfer.
Taking the data collected in Qingdao City in 2014 into the model and get supply and demand index was 0.69, and compare it with the balance index of supply and demand 0.48, it is found that the values are significantly higher than the equilibrium index, that is consistent with the actual situation of the serious water shortage of Qingdao.

Below, we will explain the scarcity of water resources in Qingdao city caused by environmental and social factors from two aspects of the physical shortage and economic shortage.

Result Analysis

Physical Shortage

Environmental Factors

The distribution of water resources in China has the characteristics of uneven space-time distribution. In spatial distribution, water resources in China in geographical location divided into two parts, North and South, the southern population accounted for 55% of the country, and the population in the north is 43%. However, approximately 4 / 5 of the water resources are distributed in the South, and 2 / 3 of the cultivated land in the north. In the time distribution, the seasonal distribution of rainfall in China is uneven. This feature makes it difficult to effectively store and distribute rain in the north of China.

Qingdao is one of the serious water shortage cities in the north of china. Qingdao City, the average precipitation for 688.2mm, the total amount of water resources is 22.1 billion cubic meters, of which annual average surface water resources amount for 16 billion cubic meters, average annual groundwater resources in the amount of 9.29 billion cubic meters, the repeated calculation between the two is 3.19 billion cubic meters. The city's per capital water resources amount to 313 cubic meters, per unit of area for possession is 306 cubic meters, respectively, only accounting for the national average of 12% and 15%.

Tab.3 Annual average water resources in Qingdao

Administrative division	precipitation		Surface water Resources amount (10^9 m3)	Groundwater Resources amount (10^9 m3)	Repeated calculation (10^9 m3)	Total amount of water resources (10^9 m3)
	mm	(10^9m3)				
Four districts of the city	728.1	1.03	0.34	0.18	0.13	0.39
Original Huangdao District	737.1	2.08	0.51	0.21	0.09	0.63
Laoshan District	861	3.35	1.46	0.66	0.41	1.71
Chengyang District	698	2.92	0.83	0.47	0.16	1.14
Jiaozhou District	686.1	8.3	1.52	1.06	0.41	2.17
Jimo District	678.5	11.72	2.68	1.29	0.54	3.43
Pingdu District	638.7	20.22	3.28	2.41	0.36	5.33
Laixi District	678.8	10.33	2.13	1.36	0.37	3.12
Original Jiaonan District	743.7	13.36	3.25	1.65	0.71	4.18
The whole city	688.2	73.32	16	9.29	3.19	22.1

Data source: Qingdao City, Development and construction of the comprehensive utilization of water resources in "Eleventh Five-Year"

According to the “Qingdao city ‘Twelfth Five-Year’” comprehensive utilization of water resources development and construction planning", in Qingdao, average annual available water resources is 1.488 billion cubic meters, accounted for about 67% of the total amount of water resources. The city's per capital use water resources quantity is approximately 171 cubic meters, lower than many Middle Eastern countries (Fig.3); the per capital available amount of water resources in east coast of Qingdao city is only 3.4 billion cubic meters / year, less than half of Kuwait's value.(8 cubic meters / year).

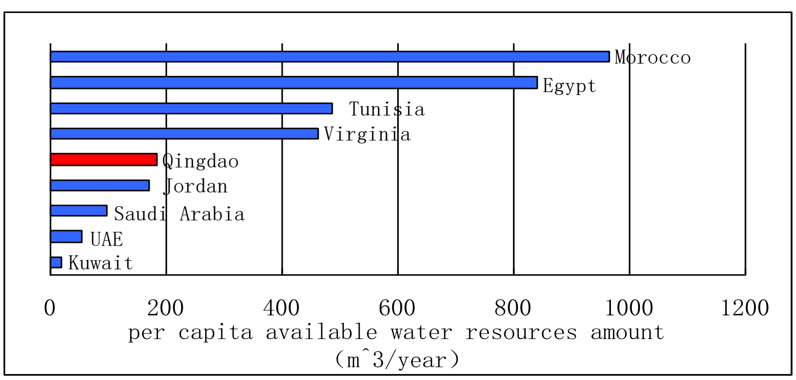

Fig.3 Per capital available water resources amount

Social Factors

Water pollution situation is grim. According to the annual monitoring data in 2014, the comprehensive evaluation of 77 river sections in Qingdao city was carried out, which, river length in line with first grade water quality standard accounted for only 3.3% of the total detected river length, with second grade standard accounted for 34.9%. In addition, in 48 large and medium-sized reservoirs, only 5 in accordance with excellent grade water quality standards, only 10.4%. Thus, the water pollution situation in Qingdao city is very serious, leading to its natural water resources to a certain degree of pollution, thereby the availability of natural water resources is reduced, and the direct supply is reduced.

Physical shortage of environmental factors and social factors that led to the shortage of natural water resources in Qingdao, the performance is a lower direct supply.

Economic Shortage

Environmental Factors

Desalination and rainwater harvesting technology need to be improved. Qingdao is a coastal city, utilization of seawater has a certain foundation, but the scope of its utilization of sea water needs to be further expanded. Statistical Yearbook of Qingdao City in 2014 and the relevant calculation show that now of seawater in Qingdao City, the direct use amount is 12 billion cubic meters / year, sea water desalination utilization amount is 0.01 billion cubic meters, the average conversion rate of seawater to fresh water is 5%. Therefore, the contribution rate to the amount of seawater desalination for the supply of water resources in Qingdao City is only 0.1%.

As early as in the 60's, it has been paid more attention to the collection and use of rainwater and put into practice abroad. However, China's Urban Collection and utilization of rain started late, even so far, many regions and cities have not paid enough attention to this. At the same time, in Qingdao which is land in the north of China, due to the uneven rainfall, it is difficult to effectively store and distribute the rain water. Thus, rainwater harvesting has little contribution to the water supply.

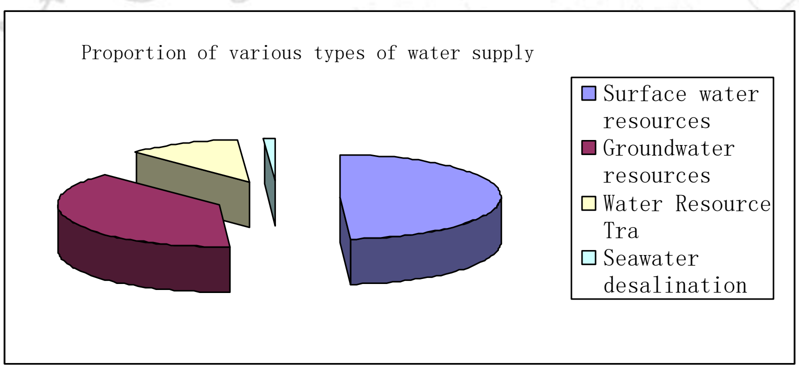

Fig.4 Proportion of various types of water supply

Social Factors

The limited scope of the reclaimed water, call transfer water approaching the limit. Reclaimed water is a part of unconventional water sources, there is still a large resistance in the use of the process: first of all, the lack of incentive policies, and the cost of reclaimed water and natural water is not a big difference, the enthusiasm of the user to use reclaimed water needs to be improved; moreover, recycled water investment recovery period is longer, so enterprises and institutions enthusiasm is not high; finally, the lack of policy and financial support, resulting in the development of recycled water is not good.

Diversion project is a key project in "the Seventh Five Year Plan" of Shandong Province during the period, although the project for the supply of water resources in Qingdao have a greater supply, but data show that the Yellow River's mining rate has reached 70%, far more exceeds its maximum load. At the same time, the Yellow River water quality and water conditions are not optimistic. Therefore, transfer water resources in Qingdao city is close to saturation.

This part of the social factors and the environmental factors constitute an indirect supply. Because it is limited to the level of technology and cost, this part of the supply of the proportion of the total supply is very low.

With the development of society, urbanization rate increased, the scale of urban population and the scale of industry are increasing continuously, but per capital water change rate, change rate of water consumption per unit is high, on the contrary, the water use efficiency was not significantly improved; at the same time, because of the limitation of irrigation technology, the proportion of agricultural water saving area and the effective coefficient of irrigation water have also been restricted. The above three aspects correspond to the large demand of water consumption, industrial water consumption and agricultural water consumption.

Tab.4 Economic, social and water resources in Qingdao

Year / Index	2005	2010	2015
Gross national product (10^9 Yuan)	2695.82	5666	10000
Permanent population (10^4 people)	740.91	871	950
Urbanization rate (%)	58.5	66	75
Water demand (10^4 m^3/ d)	91	139	198

Data source: Qingdao City National Economic and social development twelfth five year plan

In summary, under the combined effect of physical and economic shortages, the demand for water in Qingdao city is greater than the supply of water, which leads to severe overloading of water resources in the region, the water environment is not optimistic.

Problem III Forecasting Model of Water Resources

Analysis Approach

To solve the water-scarce problem more completely, besides social factors of water shortage, we incorporate environmental drivers into account, and use the model of problem one to carry out Hydro Logical Prediction on the selected regions in problem two. To this end, we take all factors set forth in problem one into condition to predict the total water demand and total water supply, then calculating the index of supply and demand, get the status of water resources in the area. Finally, explain the impact of the situation on the residents' lives.

Model Preparation-Prediction Principle and Basis

- Take social-economic development indicators of the planning level years as the basis, and give overall consideration of water demand on developing social, economic, environmental and other departments.
- Take water use quota of the developed and moderately developed countries, and the long term water demand of our country as a reference.
- Fully consider the advance of urbanization process, the strategic adjustment of economic structure and the influence of scientific and technological progress on the influence of water demand in the future

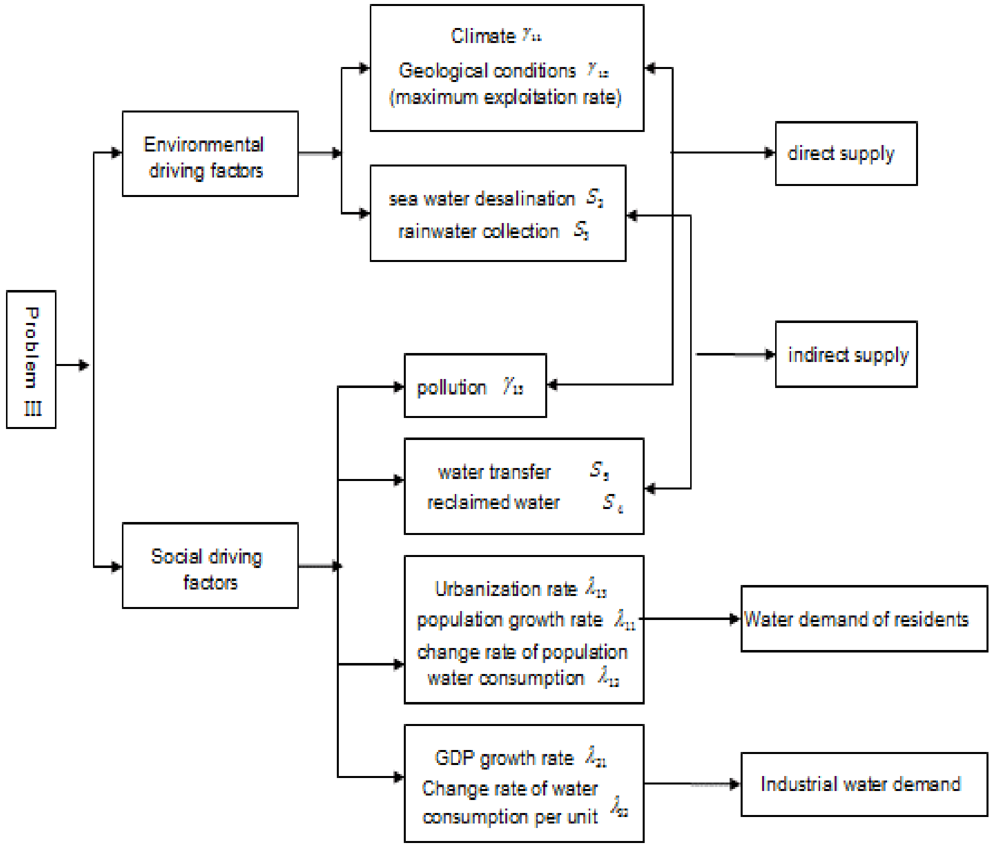

Fig.5 Flow chart of forecast analysis

Model I Establishing and solving-Water Demand Forecast

Water Demand of Residents

According to the water resources bulletin of Qingdao City, we see that residents' living water consumption increased year by year. There are three reasons for the consistent growth of per capital water consumption: the increase of population, the degree of urbanization, the improvement of living standards. So we choose the three indicators of population growth rate, per capital water consumption rate and urbanization rate to forecast the water demand of residents.

The growth rate of residents living water is a regular in a certain range, so we can use the comprehensive analysis method to predict the future water demand. This method considers both the water population and water demand quota.

The calculation formula is as follows:

$$W_1 = \lambda_{13} D_1 (1 + \lambda_{11})^n \lambda_{12} K$$

Among them, W_1 is the total amount of water needed for urban life in one particular year; D_1 is Water demand of residents in the horizontal year; K is comprehensive quota of urban domestic water consumption in the level; n is the year of forecasting.

The Forecasting of λ_{11}: Box-Jenkins Prediction Method

B-J model is a kind of short term forecasting method with high precision. The basic idea is that: some time series are dependent on a cluster of random variables of the time. Although the single sequence value of this sequence is uncertain, there is certain regularity in the variation of the whole sequence, and can be described with the corresponding mathematical model. Through the analysis of the mathematical model, it is more essential to understand the structure and characteristics of time series, and to achieve the minimum variance.

The data we used is the natural growth rate of population in Qingdao city in 2005-2014.The natural population growth rate prediction model was established with the B-J model, and the ADF test was carried out to obtain the credible population growth rate. We apply Box-Jenkins method in the application of common model forms: Autoregressive Moving.
Average Model:

$$y_t = \varphi_1 y_{t-1} + \mathrm{A} + \varphi_p y_{t-p} + \mu_t - \theta_1 \mu_{t-1} - \cdots - \theta_q \mu_{t-q}$$

Parameter φ_1, A, φ_p are the estimated auto regressive parameters; θ_1, θ_q are the estimated moving average parameters; residual μ_t is white noise sequence; q is Moving average order.
Use EVIEWS software to process data：

Tab.5 2005-2014 Resident population growth rate of Qingdao

year	population growth rate	year	population growth rate
2005	0.00634	2010	0.01246
2006	0.00660	2011	0.00511
2007	0.00623	2012	0.00498
2008	0.00534	2013	0.00496
2009	0.00563	2014	0.00575

Calculate the predicting λ_{11}=0.00635

Prediction of λ_{12}

According to "China water resources and sustainable development", the standard of China's predict water consumption predicted in different stage, we forecast per capital water consumption in China till 2030. Based on this data as table 6, we use the least square method to estimate the change rate of per capital water consumption in Qingdao, calculate λ_{12} =0.00427.

Tab.6 Per capital water consumption of urban and rural residents (L/per*d)

index /year	2000	2010	2020	2030
Per capital water consumption of urban residents	223	250~260	270~280	290~300
Per capital water consumption of rural residents	128	145~150	150~155	155~160

Prediction of λ_{13}

According to the prediction of "Macro Economic Blue Book " released by China Academy of Social Sciences in 2009, by 2030 China's urbanization rate will reach 67.81%, and 68% may be the top of next 20 years of China's urbanization development. But the data show that the urbanization rate of Qingdao in 2014 has reached 70%.It is a higher level. Therefore, we assume that in 2030, Qingdao City still maintain such a rate of urbanization, which is above λ_{13} =0.7.

We have predicted the value of all the unknown parameters after 15 years. According to the data collected from the Qingdao Municipal Bureau of Statistics, the data and the estimated parameters are brought into the model to predict the water demand of residents in Qingdao city in 2030 , calculated W_1 =6.98 billion m^3/year.

Industrial Demand

Industrial water demand increases with the increase of the scale of industry, so it must be related to the GDP growth rate and the rate of increase in the unit industrial value. We assume that both of these products have a linear effect on industrial water demand. We use the trend method to calculate future industrial water demand, Its formula is:

$$W_2 = \lambda_{21}\lambda_{22}D_2$$

Among them, W_2 is one year industrial water demand; D_2 is industrial water demand in the horizontal year.

λ_{21}, λ_{22} can use data of 2005-2014 years, and use the least squares method to estimate, gets λ_{21}=0.08, λ_{22} =0.01, and then check the level of industrial water demand in 2030 Qingdao industrial water demand $W_2 = 5.27$ billion m^3/year.

Agricultural Demand

There are much report calculations show that the water demand of residents will be the largest part of total water demand in the future, and agricultural water demand will remain basically stable. Therefore, we assume that the agricultural water demand does not change, that is, replaced by the agricultural water demand in 2015. W_3=4.02 billion m^3/year.

Above, the total water demand has been fully predicted and completed：

$$\mathrm{W} = W_1 + W_2 + W_3 = 16.27 \text{ billion m^3/year}$$

Model II Establishing and solving-Water Supply Forecast

Direct Supply

Climate change, exploitation rate and pollution are the three factors that influence the direct supply. Among them, because the impact of climate change cannot be quantified, and climate change in 15 years will not meet a big change, so we assume that climate conditions do not affect the amount of precipitation in Qingdao City

It is generally considered that the exploitation rate of surface water resources is 0.4, which is a warning line for the development of river water resources. It is generally believed that the development and utilization of surface water resources will be at high risk of ecosystem when more than 55%. Due to the water shortage situation in Qingdao city, we will use the maximum production rate to calculate. When the production rate is 55%, the water supply of the average surface water resources of Qingdao city is 8.8 billion m^3/year。In the same way, the amount of groundwater resources in Qingdao city is 5.83 billion m^3/year.

However, because of the existence of water pollution, not all available natural water resources are able to provide pure water to meet the needs of the population. It has lost the ability to provide pure water for the population at the level of heavy pollution and serious pollution. In recent years, the pollution emission coefficient of Qingdao city has reached 25%.And, we hold a pessimistic attitude that the proportion of the next 15 years will not be reduced.

Thus, the direct supply provided by the natural water resources $S_1 = 0.75 * (8.8 + 5.83) = 10.9725$ billion m^3/year.

Indirect Supply

Indirect supply includes desalination, rainwater collection, water recycling, and water transfer. Among them, the regeneration and external water quantity will not meet a big change in a short period of time. So we do not forecast this two parts, taking the data of 2015 into the model. So the forecast of desalination and rainwater collection will serve as a key part of our forecast.

Sea Water Desalination (S_2) Predicting

In the current study, there are not too many results on the prediction of sea water desalination, we adopt linear prediction method to forecast the sea water desalination with the data of 2005-2014 years.

Tab.7 2005-2014 Scale of sea water desalination of Qingdao

Year	Scale (10^9 m^3/year)	utilization of sea water desalination (10^9 m^3/year)	average conversion rate
2005	9.78	0.013	0.05
2006	9.82	0.015	0.05
2007	9.76	0.012	0.06
2008	10.03	0.014	0.06
2009	11.75	0.018	0.07
2010	11.43	0.027	0.09
2011	12.56	0.035	0.11
2012	13.89	0.038	0.10
2013	14.02	0.042	0.12
2014	14.38	0.047	0.13

Data source: Qingdao statistical yearbook 2005-2014

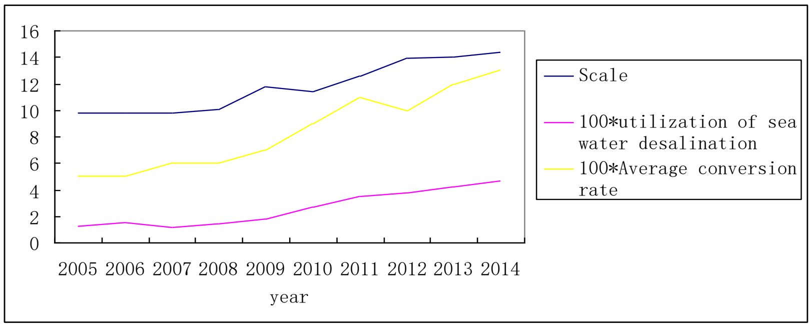

Fig.6 Data prediction of seawater desalination in Qingdao

Using EXCEL to calculate the respective change function:

$$Q_1 = 0.9576N + 3.1333$$
$$Q_2 = 0.4224N + 0.2867$$
$$Q_3 = 0.6028N + 8.4347$$

Q_1, Q_2, Q_3 representing sea water desalination scale, utilization of sea water desalination, average conversion rate.; Letter N represents the year.

As a result, we can get the amount of water resources that can be provided by the sea in 2030 $S_2 =$ 0.069 billion m^3/year.

Rainwater Collection (S_3) Predicting

Because this part of the data is difficult to collect, we will replace it with the product of the average annual rainfall and the existing technical coefficient of rainwater water collection to represent the water resources provided by the rain water collection, that is:

$$S_3 = \alpha R$$

Due to the neglect of the climate change on rainfall, the data shows that the average annual rainfall in Qingdao has maintained a stable level. We take the average annual rainfall of 2005-2014 as the average annual rainfall in 2030, calculate the amount of water resources provided by the rainwater collection in 2030 is $S_3 = 0.007$ billion m^3/year.

At this point, the total amount of water has been completed in the forecast.

$S = S_1 + S_2 + S_3 + S_4 + S_5 = 15.87$ billions m^3/ year

According to the model of Problem One, the water resources supply and demand index of Qingdao city in 2030 was obtained:

$$\mathrm{I} = \frac{W}{S} = 1.0$$

It is significantly greater than the balance of supply and demand index. This shows that in 2030, Qingdao's water supply is still a big gap.

Impact on the Lives of the Residents

Human life in the basic necessities of life is inseparable from the boiling water, and industrial and agricultural production cannot be separated from the water. Therefore, the shortage of water resources will not only have a negative impact on the living environment and quality of life of the residents, but also affect the development of agricultural production and hinder the development of the industry, and then affect the progress of the city, so that the living conditions and quality of the residents cannot be improved.

Problem Ⅳ Intervention Program & Forecast

Model Preparation-Construction of Price Index

In order to design an intervention program which takes all water driving factors into consideration, we regard water resources as a kind of commodity, the commodity supply and demand mainly dominated by the price. We construct a balance model between supply and demand. The model considers all the environmental and social factors affecting water resources mentioned in problem one, two and three. We define a price index, all the environmental and social driving factors affect the supply and demand of water resources by influencing price index directly.

$$P_t = \alpha + \sum_{i=1}^{6} \beta_i A_{it}$$

Here the price index is similar to the utility function of risk aversion investors in the investment subject.

$$\mathrm{U} = \mathrm{E(r)} - \frac{1}{2} A\sigma^2$$

A is risk aversion index, if A is large, indicate investors are more risk averse, under the same level of risk, the need for more returns E(r) to compensate the risk; if A remains unchanged, when the variance σ^2 gets bigger, utility U becomes low, investors feel less satisfied. Similarly, in our price index, A_{it} measure the impact of environmental and social drivers on water resources, similar to the variance σ^2, when $\beta_i > 0$, the greater the A_{it} is,the higher the price P_t should be. β_i is the quantitative measure of the effect of driving factors, we use the regression coefficient of driving factor and water demand (or supply) to measure, β_i is equivalent to the investor aversion index A of the utility function, if $\beta_i > 0$, illustrate the driving factor of demand or supply to produce positive effect, making price index produced a positive premium, that means the driving factor's increase will rise the P, so there will be more water supply, relieving the water shortage situation. On the contrary, if $\beta_i < 0$, the drive factor's increase will decline the P ; in addition, the bigger $|\beta_i|$ is, illustrate same change of the driving factors will increase the change amplitude of P, making water demand or supply changes more obviously. In a word, if $\beta_i > 0$, the greater β_i is, the greater rise of P; if $\beta_i < 0$, the greater $|\beta_i|$ is, the greater decline of P.

Letter α represents the constant price of water resources determined by the original demand and supply without considering those driven factors of water shortage. Here we assume that it is 0.2. Letter t represent the time factor.

When $\mathrm{i} = 1{:}3$, A_{it} means demand factor, including the population growth rate A_{1t} , the urbanization rate of A_{2t} , change rate of unit industrial value added A_{3t} , β_i is the regression results of demand factor and the corresponding demand; When $\mathrm{i} = 4{:}6$, A_{it} represents factors affect the supply, including the pollution coefficient A_{4t} and reclaimed waterA_{5t} ,transfer water A_{6t} , β_i is the regression results of factor affecting the supply and the corresponding supply.

Model Establishing

Construction of Water Resources Demand Curve

On the demand side, select different driving factors, such as selecting the population growth rate A_{1t} and the resident water need D_{1t} from 2005 to 2014. Factor coefficient β_1 are obtained according to the linear least square method. Similarly the factor coefficient β_2 of the rate of urbanization A_{2t} and industrial water coefficient D_{2t}can obtained. So as $\beta_3$the factor coefficients of per unit of industrial value increase change rate A_{3t} and the change rate of industrial water D_{2t} .Thus $P_t = \alpha + \beta_1 A_{1t} + \beta_2 A_{2t} + \beta_3 A_{3t}$, because aggregate demand$D_1 = D_{1t} + D_{2t} + D_{3t}$, therefore we can get a corresponding points (P_t, D_t) of prices and aggregate demand of time *t.* Fit the corresponding points at different times and we can get the total demand curve $D_t$of water resources.

Construction of Water Resources Supply Curve

On the supply level, supply of natural water resources S_{1t} is mainly affected by the pollution. Therefore we select the data of pollution coefficient A_{4t} and natural water resources from 2005 to 2014. Using Linear Least Squares method for regress, get the regression coefficient β_4, Indirect supply mainly constituted by the desalination of sea water S_{2t}, rain water collection S_{3t}, regeneration S_{4t} and external water S_{5t}, total supply $S_t = S_{1t} + S_{2t} + S_{3t} + S_{4t} + S_{5t}$, So similarly, through regress get the coefficient β_5 of reclaimed water A_{5t} and aggregate supply S_t , coefficient β_6 of water diversion A_{6t} and supply S_t .Thus $P_t = \alpha + \beta_4 A_{4t} + \beta_5 A_{5t} + \beta_6 A_{6t}$, therefore we can get a corresponding points $(P_t , S_t)$of prices and the total supply at time t .Through polyfit the corresponding points at different times and we get the total supply curve S_s of water resources.

From the previous analysis, the effect of any driving factor on the demand and supply can be internalized as the price index, to further influence the demand and supply of water resources by affecting the price index. Therefore, our intervention plan is to regulate the price index, according to the demand curve and the supply curve, adjust the demand and supply of water resources indirectly, so as to realize the balance between supply and demand of water resources.

Specific Intervention Program

According to the topic, we still take Qingdao as an example to analyze, because Qingdao is a serious water shortage city, we mainly design the intervention program from the perspective of increasing the supply of water. In the direct supply of water, due to the limited natural water resources, there is a limit to the maximum exploitation rate, there is not much room for transformation, so we mainly intervene in the indirect supply. In order to consider both the environmental factors and social factors, we select the rainwater collection and reclaimed water as the main intervention.

Intervention Program of Rainwater Harvesting

Qingdao is a serious water shortage city, per capital annual water resources is only 248 cubic meters, it is 9% of that in China. And the distribution of water resources is extremely uneven in the year. Atmospheric precipitation is the main supply source of water in the city, but at present, the utilization rate of rainwater is insufficient, a lot of rain water is directly discharged into the sea, so there is a considerable potential of the development and utilization of rainwater.

The collection of rainwater mainly depends on the rainfall and the technology of rainwater collection, the rainfall cannot be controlled, so it is mainly to improve the technology of rainwater collection. By using 2005-2014 year data, calculate the regression coefficient β_3 between the rainwater collection technology and the total supply is 0.0936, this shows that the rainwater collection technology every 1% rise will increase the total supply of 0.0936 units. At this point, A in the price index is refer to the rainwater collection technology change rate of different years. Because we are using 2005-2014 years of rainwater collection technical data, bring it into the price index function can get 2006-2014 price index, then bring the price index into the supply function to obtain supply changes in 2006-2014 years caused by rainwater collection technology change rate.

Thus, by affecting the growth rate of rainwater collection technology can affect the price index and affect the total supply further. It can not only verify the influence of the change of the technology of rainwater collection in the past, but also can adjust the future supply by forecasting the future rainwater collection technology change rate. And the growth of rainwater collection technology can be optimized from three angles of rain infiltration, rainwater collection and rainwater purification.

Intervention Program of Reclaimed Water

Reclaimed water has become an important source of water supply in Qingdao. The utilization rate of reclaimed water is mainly affected by the construction of the infrastructure: the regeneration of the water pipe network, the new pumping station, and the influence of the sewage treatment technology. Therefore, the intervention of reclaimed water can be started from these aspects. We use urbanization rate to measure the infrastructure construction, weighted both urbanization rate and sewage transformation technique the weight of 0.5, obtained a comprehensive drive index of reclaimed water, the regression coefficient β between the comprehensive index and the aggregate supply is 0.072, it shows that this comprehensive index changes one unit, will cause the change of the total supply of 0.072 units. In the same way, the change of the total supply caused by the different urbanization rate and the technological change rate of sewage conversion in Qingdao during 2006-2014 could be calculated.

Therefore, we can increase the investment of infrastructure, improve the production process of monomer to save water, improve the conversion rate of sewage and so on, so as to improve the indirect supply of water resources. And through the model can calculate the specific amount of increased total supply, which can provide a reference for the subsequent investment.

Other Interventions

In addition to the above two kinds of schemes, there are many other ways such as water diversion intervention, intervention for desalination of sea water, pollution control intervention, price intervention. In fact, all the driving factors of the model can be intervened, and can be divided into the intervention of the supply side and the demand side.

The Influence of Intervention Plan

For the mainly discussed two intervention programs, rainwater collection will make the rainwater utilization more efficient and reduce dependence on other sources of water resources, such as water diversion, meanwhile, reducing the dependence on water resources of the surrounding countries, reduce the water pressure of the surrounding area. In addition, more efficient use of rainwater will directly or indirectly increase the capacity of rainwater infiltration, rainwater collection.

The better infiltration of rain makes the local greening and landscape water more sufficient, the ability to clean up the air and the ecological environment can be improved. As for seawater desalination intervention program, the improvement of the sea water desalination technology can provide more available water supply, reducing the dependence on freshwater resources. And reduce mining pressure as well as the possibility of damage to the geological environment.

Evaluation of the Intervention Plan

Advantages

First, our intervention program through applies price index as a medium, take all the factors that affect the supply of water resources into consideration. In the design of intervention policy, all factors can be integrated to make a more systematic analysis. When an intervention program may have adverse effects, other interventions can be used to make up.

Secondly, we construct the balance of supply and demand model, regard water resources as a kind of commodity. From the viewpoint of macroeconomics, analyze the specific changes in the supply and demand of water resources quantitatively, that is caused by different driving factors.

Finally, two specific intervention plan were designed from the angles of environmental factor and social factor that affect the water shortage, which makes the analysis of the water shortage more comprehensive and specific.

Disadvantages

In the design of the model, the specific data are used to solve the problem, but there are some errors in the process of index selection and data filtering, so the accuracy of calculation results is reduced.

Result Analysis

Take relevant data of Qingdao from 2005 to 2014 into the model constructed in problem four to forecast the supply and demand function of water resources over the next 25 year, and here is the result.

$$S_S = -3.8908P_t^3 + 7.4085P_t^2 - 1.7824P_t + 0.508$$

$$Q_d = -2.7803 + 4.9195P_t - 0.4963$$

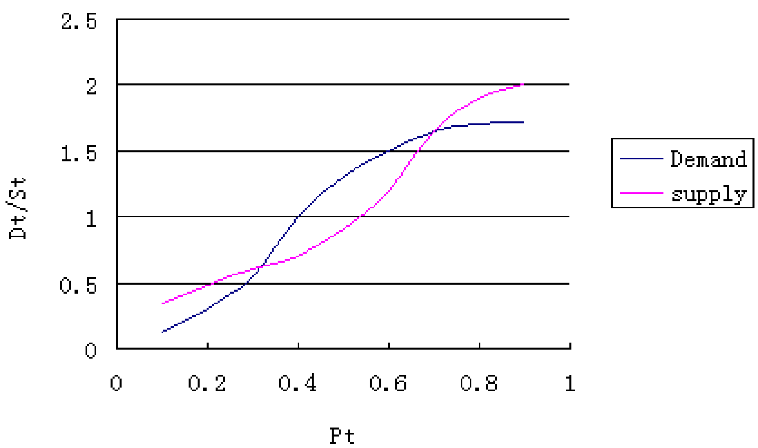

Fig.7 Prediction of water resources in the next 25 years in Qingdao

Make $Q_d = S_S$, get two points, they are E_1(0.27,0.6), E_2(0.75,1.6)

Set demand equals supply, we get two equilibrium points, it can be learned that in a relatively short period of time, the intervention plan can only make up water shortage of resources, and cannot make the supply greater than demand and completely solve the problem of water shortage. But in long term, in the year of 2035, which equilibrium points E_2represent, the supply will finally surpassing the demand. In other words, before the year of 2035, we will still suffer a water scarcity, but water situation eased over the time with the improvement of supply, and there will be sufficient water supply to match demand by 2035.

Evaluation of the Model

The Advantages of Model

- Our model is simple and consistent with common sense, applying the theory of supply and demand balance to practical issues flexibly, which makes it easy to operate and solve problem.

- In the process of model building, consider the influence of various water shortage driving factors comprehensively, and the model has better integrity and application.
- We creatively define the price index, regard water resource as a commodity, internalized all the driving factors as the price index, so we can analyze the impacts on water demand and supply more directly and systematically.
- The intervention plan is targeted and has a positive effect on solving water shortage.

The Disadvantages of Model

- The model has strict requirements for the data, but the relevant data cannot be provided in some areas, so the extension of the model can be reduced.
- Due to the limitation of time and data, we have taken the simplest way to analyze some complex factors, so that the model has lost the accuracy to some extent.

Future Work

For the prediction of λ_{13} in problem three, we according to the existing authority forecast data, combined with data of Qingdao to assume, that by 2030 in Qingdao, the urbanization rate is 0.7, but in fact the index value may not be the case. To this end, we performed sensitivity analysis, discussing the supply and demand index size under different urbanization rate.

For convenience, we simplify the model, and use the EXCEL to draw the change, as shown in Fig.8.

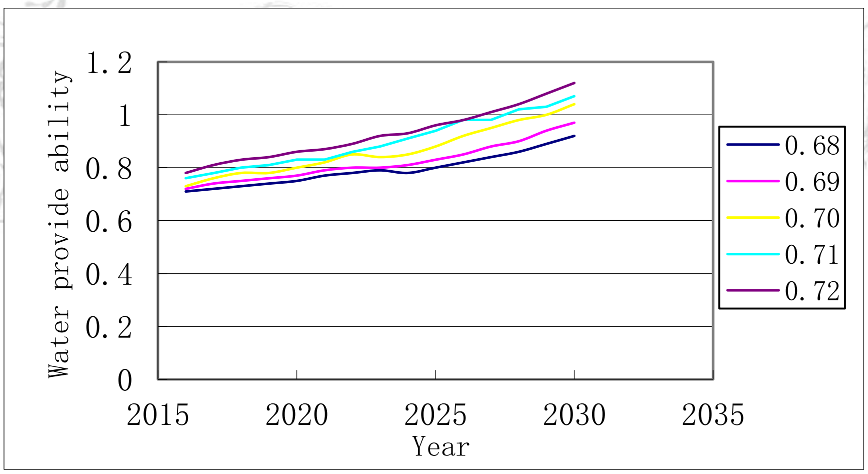

Fig.8 Supply and demand index under different urbanization rate

The results of sensitivity analysis show that the urbanization rate is different, the supply and demand index will change, but the overall trend is the same. As we can see, with the growth of the forecast year, the error of the model is more and bigger, so we will improve the model in this aspect in order to get more accurate model.

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