Research on supply and demand balance of water resources in Beijing-Tianjin-Hebei Region

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Abstract. The Beijing-Tianjin-Hebei region, as the largest city group in the north of China, however, the shortage of water resources is a shortcoming that restricts the sustainable development of the Beijing-Tianjin-Hebei region. How to realize the rational allocation and optimization of water resources in the context of the coordinated development of the Beijing-Tianjin-Hebei region is a key issue that needs to be resolved in the coordinated development of the Beijing-Tianjin-Hebei region. Based on a preliminary analysis of the characteristics of the temporal and spatial changes in water supply in the Beijing-Tianjin-Hebei region from 2001 to 2016, this study established the System Dynamics (SD model) for the supply and demand balance of water resources in the Beijing-Tianjin-Hebei region, and simulated three different scenarios, namely traditional scenario, development scenario, and sustainable scenario. Forecasting the supply and demand of water resources in the Beijing-Tianjin-Hebei region under different scenarios from 2016 to 2030, according to the forecast results, extracting the dominant factors and proposing an optimal control strategy for the water-supply-demand balance configuration model for the coupling of SD in the Beijing-Tianjin-Hebei region. This study can provide useful exploration for enriching and improving the interaction mechanism of economic-social-resource-environment system, and provide reference for the balance of supply and demand of water resources in similar water-scarce areas in the world.

1. Introduction

The United Nations World Water Development Report 2016 pointed out: "Sustainable management of water resources, water infrastructure and access to safe, reliable and affordable water and health services can improve people's lives and promote regional economic development. Sustainable management of water resources is also necessary to achieve green growth and sustainable development. On the contrary, neglecting water issues will have a serious negative impact on the economy, livelihoods and people, which may result in heavy and extremely expensive costs [1-4]. As far as China is concerned, water resources have been juxtaposed with energy and environment, and become the three major restrictive factors affecting the sustainable development of China's economy and society. Therefore, how to realize the rational utilization and management of water resources has become an important topic in the field of world water resources research, which has aroused extensive discussion among scholars at home and abroad [5-7].

Therefore, on the basis of fully collecting and sorting out the data, this study analyzed and predicted the balance between supply and demand of water resources in Beijing, Tianjin and Hebei,
focused on the contradiction between supply and demand of water resources in Beijing, Tianjin and Hebei, and discussed the existing problems in the development and utilization of water resources and the direction for improvement, so as to coordinate the relationship between the development of Beijing, Tianjin and Hebei and the utilization of water resources[8-10].

2. Models and methods
The data come from Beijing Water Resources Bulletin (2000-2016), Tianjin Water Resources Bulletin (2000-2016), Hebei Water Resources Bulletin (2006-2016), Beijing Statistical Yearbook (2002-2017), Hebei Statistical Yearbook (2002-2017), and Tianjin Statistical Yearbook (2002-2017).

The simulation model used in this study is System Dynamics (SD model). The spatial scope includes the administrative areas of Beijing, Tianjin and Hebei. The time span is 2001-2030, and the base year is 2016. The historical statistical year is 2001-2016, the simulation prediction year is 2017-2030, and the simulation time step is 1 year. In this study, 66 variables were involved, among which, the historical data of each variable from 2001 to 2016 were collected as the basic data. Based on the investigation and study of Beijing-Tianjin-Hebei region, this study divided the interaction mechanism levels of water resources system in Beijing-Tianjin-Hebei region, and uses SD model to construct Beijing-Tianjin-Hebei region. Causal Feedback Diagram of Regional Water Resources Supply and Demand (figure 1) and Flow Diagram (figure 2).

![Causal Feedback Diagram of Regional Water Resources Supply and Demand](image1)

**Figure 1.** Water supply and demand balance causality feedback diagram in Beijing-Tianjin-Hebei Region
3. Results and discussion

Simulation and analysis of water resources supply and demand balance trend is reconstructed for Beijing-Tianjin-Hebei Region. According to the development trend of Beijing-Tianjin-Hebei region, the traditional scenario, the development scenario and the sustainable scenario were determined. The idea of traditional scenario is that the water supply and demand system in Beijing-Tianjin-Hebei region will remain unchanged, and the current policy, water supply and consumption level and economic growth rate will be maintained. The idea of the development-oriented plan is that the Beijing-Tianjin-Hebei region is the leader of China's economic and social development. Therefore, the development-oriented plan is to adjust the growth rate of various industries to a higher level on the basis of the traditional model and economic growth as the starting point. The idea of sustainable scheme is to explore the suitable development mode of Beijing-Tianjin-Hebei region based on the traditional scheme and the development scheme.

3.1. Water Resources Supply and Demand Balance Analysis

Figure 3 shows the water supply and demand gap in Beijing-Tianjin-Hebei region under different scenarios forecasted by SD model. Under the traditional and developmental scenarios, the change trend of water resources gap is "expansive", while under the sustainable scenario, the change trend of water resources gap is "contractive". Under the sustainable scenario, there is a gap in the water resources system in 2016-2022. With the development of economy and society, the gap is getting smaller and smaller. There will be a big turning point in 2020. After 2022, the supply and demand of water resources will exceed the demand, and there will be no gap. Thus, sustainable development is considered. The ideal development mode under the premise of water resources supply and demand system.
Figure 3. SD model water supply and demand gaps in different scenarios

3.2. Water Supply Subsystem

The change trend of reclaimed water volume and total water supply is similar. By 2030, the traditional scenario model predicts 2.08 billion cubic meters of reclaimed water, the development scenario model predicts 2.27 billion cubic meters of reclaimed water, and the sustainable scenario model predicts 4.16 billion cubic meters of reclaimed water (Figure 4). In this study, the factors that determine the change of reclaimed water quantity are the amount of wastewater recovery and the utilization rate of wastewater reclamation. The amount of wastewater recovery is positively correlated with the amount of wastewater discharged, and the reuse rate of wastewater is related to the basic conditions of wastewater reuse. In China, the use of urban reclaimed water started later than other developed countries in the world, and due to economic constraints, the cost of sewage transportation and water supply facilities has brought difficulties to the improvement of sewage utilization efficiency in Beijing, Tianjin and Hebei.

Figure 4. Water supply structure in different scenarios of SD model
3.3. Water Demand Subsystem

According to the three scenarios water consumption structure chart (figure 5 (b) (c) (d)), it can be seen that the water consumption structure under the three scenarios is basically the same. In the three scenarios, agricultural water consumption always accounts for the largest proportion of water consumption expenditure, although in the forecast year, it shows a downward trend. However, agricultural water expenditure is still far greater than other water expenditures. Ecological water use showed an upward trend, but industrial water use showed a downward trend. The demand for ecological water will exceed industrial water for the first time around 2023. Domestic water consumption ranks second among all water consumption expenditures, showing a slow rise.

![Water Consumption Chart]

Figure 5. SD model water use in different scenarios.

We can see that under the three scenarios, agricultural water use accounts for more than 50% by 2030, and traditional agricultural water use accounts for 55.4%. In developed countries, the average proportion of agricultural water use is about 43%, and there is still a big gap between Beijing, Tianjin
and Hebei. The urbanization level of Beijing and Tianjin in Beijing-Tianjin-Hebei region is high and the cultivated land area is small, so the agricultural water use in Beijing-Tianjin-Hebei region is concentrated in Hebei Province. Hebei Province is a large agricultural province, with a large amount of agricultural water and a relatively stable demand. In this study, the variables affecting agricultural water use in Beijing, Tianjin and Hebei are farmland water use and livestock water use. Farmland water use is much larger than livestock water use, and the change of livestock water use quota is more stable than that of irrigation quota. Therefore, reducing irrigation water quota is a breakthrough to reduce the proportion of agricultural water in Beijing, Tianjin and Hebei. How to change the current situation of extensive agricultural water use in Beijing-Tianjin-Hebei region and realize the fine operation of Beijing-Tianjin-Hebei region is the future development direction of agriculture in Beijing-Tianjin-Hebei region.

In this study, industrial water consumption is determined by industrial output value and water consumption per unit of industrial output value. In the case of increasing industrial output value, industrial water consumption will decrease instead, because of industrial output per unit. The value of water consumption shows a decreasing trend, indicating that the efficiency of industrial water use in Beijing, Tianjin and Hebei region is constantly improving. Ecological water use is the compensation of resources and environment. It can be seen that the ecological water use in Beijing, Tianjin and Hebei has been improved under three scenarios in the forecast period, which is due to the enhancement of environmental awareness. Under the three scenarios, the proportion of ecological water use varies slightly, all of which are about 14%. Development scenarios have the smallest proportion of ecological water use. In this study, ecological water use is determined by urban water use and artificial recharge of rivers and lakes. Urban environmental water use is predicted and calculated by urban green space area and green space water quota. The reason for the rise of ecological water use is the expansion of urban green space area.

4. Conclusion

4.1. Comparative Analysis of Three Forecast Scenarios of Water Resources in Beijing-Tianjin-Hebei Region

Based on the spatial and temporal characteristics of water supply and demand in Beijing-Tianjin-Hebei region, combined with system dynamics model, the SD model of water supply and demand balance allocation in Beijing-Tianjin-Hebei region. Three scenarios are simulated to simulate the water resources allocation, and the changing situation of water resources supply and demand in Beijing-Tianjin-Hebei region under different development demands is compared. The main conclusions of this study are as follows: The gap of water resources supply and demand in Beijing-Tianjin-Hebei region is 17*10^8 cubic meters/year under the traditional scenario by 2030; the gap of water resources supply and demand in Beijing-Tianjin-Hebei region is 30.7*10^8 cubic meters/year under the development scenario; and the water resources supply and demand in Beijing-Tianjin-Hebei region will gradually tend after 2020 under the sustainable scenario. Balance. The forecast trend of water use structure in Beijing-Tianjin-Hebei region is that the proportion of agricultural water use and industrial water use will continue to decline in the forecast period, while the proportion of domestic water use and ecological water use will increase in different degrees in the forecast period. In the water supply structure, the proportion of reclaimed water will be greatly increased in the forecast period.

4.2. Policies and Suggestions

Regarding the optimization of water use structure, the adjustment of industrial structure is the starting point of optimization. Water-saving society construction should be coordinated with economic and social development. In the process of economic restructuring, water-saving industrial system should be established to improve the comprehensive utilization efficiency of water resources through rational industrial layout. The water use structure in Beijing, Tianjin and Hebei is partly transferred. The
transfer of water use structure is related to the transfer of industrial structure. The development direction of industrial structure is to reduce water use. The expansion of economic scale and the increase of population are the factors leading to the increase of water use, while the adjustment of industrial structure and the improvement of water use efficiency are the factors to alleviate the pressure of water use.

Regarding the optimization of water supply structure, the utilization of reclaimed water is the starting point of optimization. The improvement of the utilization efficiency of reclaimed water can effectively increase the water supply, which is an optimization of the water supply structure. The improvement of the utilization efficiency of reclaimed water can be started from the following aspects. Firstly, the upgrading and optimization of sewage treatment technology, through increasing investment in sewage treatment, change the current situation of sewage treatment facilities far behind other countries. Advanced sewage treatment technology can greatly promote the reduction of sewage discharge and improve the efficiency of water resources utilization. Secondly, the area coverage of sewage treatment should be increased. At present, the level of sewage treatment in Beijing-Tianjin-Hebei region is quite different. By expanding the coverage of sewage treatment, when the sewage treatment can reach the coverage of the whole region, the level of sewage treatment in Beijing-Tianjin-Hebei region can be improved as a whole, thus meeting the increasing water quantity and water quality requirements.

Based on the system pressure level of "adapting measures to local conditions, adapting land to agriculture, zoning management", and based on the system pressure level of "fixing production by water, strictly abiding by the red line" multi-level optimization control policy system. The system is to adjust and improve the elements of water resources supply and demand balance in Beijing-Tianjin-Hebei region, optimize the balance of water resources supply and demand in Beijing-Tianjin-Hebei region from different aspects, and the "ecological compensation response mechanism" is to integrate the balance of water resources supply and demand and economic factors in Beijing-Tianjin-Hebei region, and adjust the interests of all parties of water resources by economic means. Under the background of Beijing-Tianjin-Hebei integration, "Regional Linkage Management" is a strategy for coordinated development of regional water resources in Hebei Province. "Sponge City System of Beijing-Tianjin-Hebei Urban Agglomeration" is a strategy of building coordinated development of "people, city, resources and environment" based on the concept of flexible city. "Suitable for local conditions, suitable for farming and zoning management" is a strategy based on the difference of background conditions and the current agricultural situation in Beijing, Tianjin and Hebei. The direction of agricultural development in Hebei Province is to strengthen the vegetable and fruit industry in Hebei Province. In the direction of agricultural development, Tianjin should take urban agriculture as its orientation and vigorously promote facility agriculture and information agriculture. Beijing's agriculture is mainly used for emergency protection, ecological leisure and demonstration of science and technology. Therefore, we should focus on developing circular agriculture, water-saving agriculture and eco-tourism agriculture. "Fixed production by water, strictly abide by the red line" is the study based on the carrying capacity of water resources to determine the type and scale of industrial development, change the driving mechanism of economic development as a single direction, implement strict water resources management system, and strictly control the total amount of water use.

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