Research and Realization of Non-traditional Water Resources Optimal Allocation Model

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Abstract: As the shortage of water resources becomes more and more obvious, it is imperative to incorporate non-traditional water resources into the water supply system. The utilization of non-traditional water resources in China is still in its infancy, and the research on the integration of non-traditional water resources into the water resources allocation system still needs to be in-depth. This paper establishes a multi-objective water resources allocation model, adopts the weighting method to convert multiple objectives into single objectives, solves the problem by particle swarm algorithm, and builds a regional non-traditional water resources allocation system by combining knowledge visualization integration platform, components, and knowledge maps. Applying it to Tianjin Binhai New Area, a water resource optimization allocation system was established in Binhai New Area, which realized the water availability of various water sources in the region, the water demand of each user in the sub-region, the calculation of supply and demand balance, and the allocation of water resources. The effect of the use of non-traditional water resources on alleviating regional water stress and the feasibility of the algorithm for co-allocation of non-traditional water resources and traditional water sources are verified, providing a basis for the allocation of non-traditional water resources.

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1 INTRODUCTION

Water is one of the basic elements of human life, but also to ensure the normal operation of all links of the entire society indispensable important resources. However, due to the rapid growth of the world population and the development of modern industries, the demand for water resources is increasing, while the availability of water resources in many areas is decreasing sharply. In addition, water pollution is serious and water resources are wasted, making water shortage an urgent problem to be solved worldwide (Gao & Yang, 2005). In order to solve the shortage of water resources, in addition to conventional water-saving measures, the development and utilization of non-traditional water resources are gradually taken as a breakthrough. Non-traditional water resources are special water sources different from traditional surface groundwater resources, mainly including sea water, brackish water, reclaimed water and rainwater. At present, the utilization modes of non-traditional water resources at home and abroad mainly include seawater desalination, direct use of seawater for industrial cooling, rainwater collection and utilization, brackish water irrigation and sewage recycling (Shao, 2017; Zhang, 2015). Due to the limitation of non-traditional water resources users, they cannot be allocated according to the traditional water resources allocation mode, and the unreasonable allocation leads to the waste and pollution of water resources. Therefore, the urgent problem to be solved for the utilization of non-traditional water resources is how to use them rationally to play the biggest role.

The research on non-traditional water resources utilization has a history of nearly 100 years and has made many achievements. Due to the large difference in water quality, non-traditional water resources have more constraints in the configuration, and the target users are relatively single, so they cannot be configured like traditional water resources. Since the 21st century, with the development of intelligent optimization algorithm theory and computer technology, Genetic algorithm (Morshed & Kaluarachchi, 2000), Ant colony algorithm (Minsker

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et al., 2000), Particle swarm optimization algorithm (Mckinney & Cai, 2002), Large-scale system theory and method (Perera et al., 2005) and other intelligent optimization algorithms have been used in the study of water resource optimal allocation, and the study of water resource optimal allocation has also developed from the study of single objective to the study of multi-objective water resource allocation. There is still a lack of research on non-traditional water resource allocation, so the utilization efficiency is not high.

Like traditional water resources, the utilization of non-traditional water resources also needs reasonable allocation. However, due to the uneven quality of non-traditional water resources, many factors, such as water quantity and water quality, are often needed to be considered when included in the overall regional allocation. The water users are divided according to the quality of non-traditional water resources, and the combined allocation of water quality and quantity is carried out to realize the maximum and optimal utilization of resources. In this paper, the allocation of non-traditional water resources was studied. Based on particle swarm optimization algorithm, a multi-objective water resources allocation model was established. With the support of knowledge visualization integration platform, component development, knowledge visualization and other technologies, a regional non-traditional water resources allocation system was developed and applied to Tianjin Binhai New Area. The solution of water resources allocation scheme of Binhai New Area and three administrative regions under its jurisdiction is realized, which provides a basis for the allocation of non-traditional water resources.

2 CONSTRUCTION OF WATER RESOURCES ALLOCATION MODEL

2.1 Configuration Model Building

2.1.1 Objective Function

(1) Economic objective: It is usually expressed in terms of maximizing the net benefit of regional water supply. The objective function is as follows:

$$max f_1(x) = max \sum_{k=1}^{K} \sum_{i=1}^{I} \sum_{j=1}^{J} x_{ij}^k \beta_j^k \left(b_{ij}^k - c_{ij}^k\right) \quad (1)$$

Where:

b_{ij}—The benefit coefficient of water supply from source i to user j in sub-region k, yuan /m^3;

c_{ij}—The cost coefficient of unit water supply from source i to user j in sub-region k, yuan /m^3;

β_j^k—The water equity coefficient for user j in sub-region k;

x_{ij}^k—Decision variable: water supply from source i to user j in sub-region k: 10,000 m^3.

(2) Social goal: The social goal is measured by the minimum total water shortage in the region. The objective function is as follows:

$$max f_2(x) = -min \sum_{k=1}^{K} \sum_{j=1}^{J} (D_j^k - \sum_{i=1}^{I} x_{ij}^k) \quad (2)$$

Where:

D_j^k—The water requirement of user j in sub-region k, 10,000 m^3.

(3) Ecological environment goal: to cause the least damage to the environment as the goal. In this paper, chemical oxygen demand (COD) is mainly taken as the pollutant index, because it can reflect the pollution degree more accurately and is relatively easy to measure. COD discharge is taken as the reference of pollution discharge, and the objective function is as follows:

$$max f_3(x) = -min \sum_{k=1}^{K} \sum_{j=1}^{J} d_j^k p_j^k x_{ij}^k \quad (3)$$

Where:

d_j^k —COD concentration in wastewater discharged by user j in sub-region k, *mg/L*;

p_j^k—Sewage discharge coefficient of user j in sub-region k.

2.1.2 Constraints

(1) Water supply capacity constraints. That is, the sum of water supply to all users from source i should not be greater than its water supply:

$$\sum_{j=1}^{J} x_{ij}^k \leq W_i \quad (4)$$

Where:

W_i —Water supply capacity from source i, 10,000 m^3.

(2) Water constraints

$$L_j \leq \sum_{i=1}^{I} x_{ij}^k \leq H_j \quad (5)$$

Where:

L_j^k—Upper limit of water demand of user j in subregion k;

H_j^k—Lower limit of water demand of user j in subregion k.

(3) Non-negative constraint of variables:

$$x_{ij}^k \geq 0 \tag{6}$$

2.1.3 Setting of Decision Variables

(1) i represents water source, and i =1,2,3,4, and 5 respectively represent local surface water, groundwater, externally transferred water, reclaimed water and desalinated seawater.

(2) j represents the water sector, and j=1,2,3 represents life, production and ecology respectively.

(3) k represents the water resources division. Binhai New Area has three administrative regions under its jurisdiction: k =1,2,3 are Hangu District, Tanggu District and Dagang District respectively.

2.1.4 Algorithm Selection

In this paper, particle swarm optimization algorithm is used to calculate the optimal configuration scheme. The water users were divided into three categories, the water supply households into five categories, and the Binhai New Area was divided into three sub-regions (Tanggu District, Hangu District, and Dagang District). Thus, the decision-making variables reached 45 dimensions. Floating-point coding is adopted, with each gene in an individual represented by one floating-point number.

2.2 Fitness Function Construction

Since water resource allocation is a multi-objective problem, it is very complicated to directly use the objective function to calculate, so it is considered to construct the fitness function to transform the multi-objective into a single objective to simplify the calculation. As the indexes of each configuration target are different in dimension and the optimization criteria are not consistent, some values are better with a larger value, while others are better with a smaller value. Therefore, first of all, the optimization criteria should be adjusted to be consistent. Among the three objectives, the economic goal is the best when the economic benefit is larger, the social goal is the best when the regional water shortage is smaller, and the environmental goal is the best when the COD discharge is smaller. Secondly, the three objective dimensions should be unified, so this paper makes the following adaptive construction of the objective function. Use the following interpolation formula to calculate the standard value corresponding to the target.

(1) Economic objectives:

$$P_1 = \frac{f_1}{f_{1max}} \tag{7}$$

Where:

P_1—The adaptive structure of economic goals;

f_1—Value of economic objective function under a configuration scheme;

f_{1max}—The maximum of the economic objective function.

(2) Social goals:

$$P_2 = 1 - \frac{f_2}{f_{2max}} \tag{8}$$

Where:

P_2—The adaptive construction of social goals;

f_2 —Value of social objective function under certain configuration scheme;

f_{2max}—The maximum social objective function.

(3) Ecological objectives:

$$P_3 = 1 - \frac{f_3}{f_{3max}} \tag{9}$$

Where:

P_3—The adaptive structure of ecological goals;

f_3—Value of the ecological objective function for a configuration.

f_{3max} — Maximum value of the ecological objective function.

After each target is converted into the standard value between 0 and 1, the fitness function can be constructed by weighting and summing these standard values, i.e.

$$F = \sum_{i=1}^{3} W_i P_i \tag{10}$$

Where:

F—Fitness function;

2.3 Model Parameter Determination

2.3.1 Water Equity Coefficient

The water equity coefficient β_j^k represents the priority degree of water supply to users. According to the importance degree of user, the water supply order is domestic water supply, production water supply and ecological water supply. The following formula can be used to transform the priority degree of water use into the water fairness coefficient.

$$\beta_j^k = \frac{1+n_{max}^k - n_j^k}{\sum_{j=1}^{J}(1+n_{max}^k - n_j^k)} \tag{11}$$

Where:

n_j^k—The sequence number of water user j in sub-region k;

n_{max}^k—Number of all users in sub-region k.

2.3.2 Target Weight Coefficient

Target weight coefficient w_i reflects the importance of target i in all targets sets in the target system. Both the sub-region weight coefficient and the target weight coefficient can be obtained by using the analytic hierarchy process.

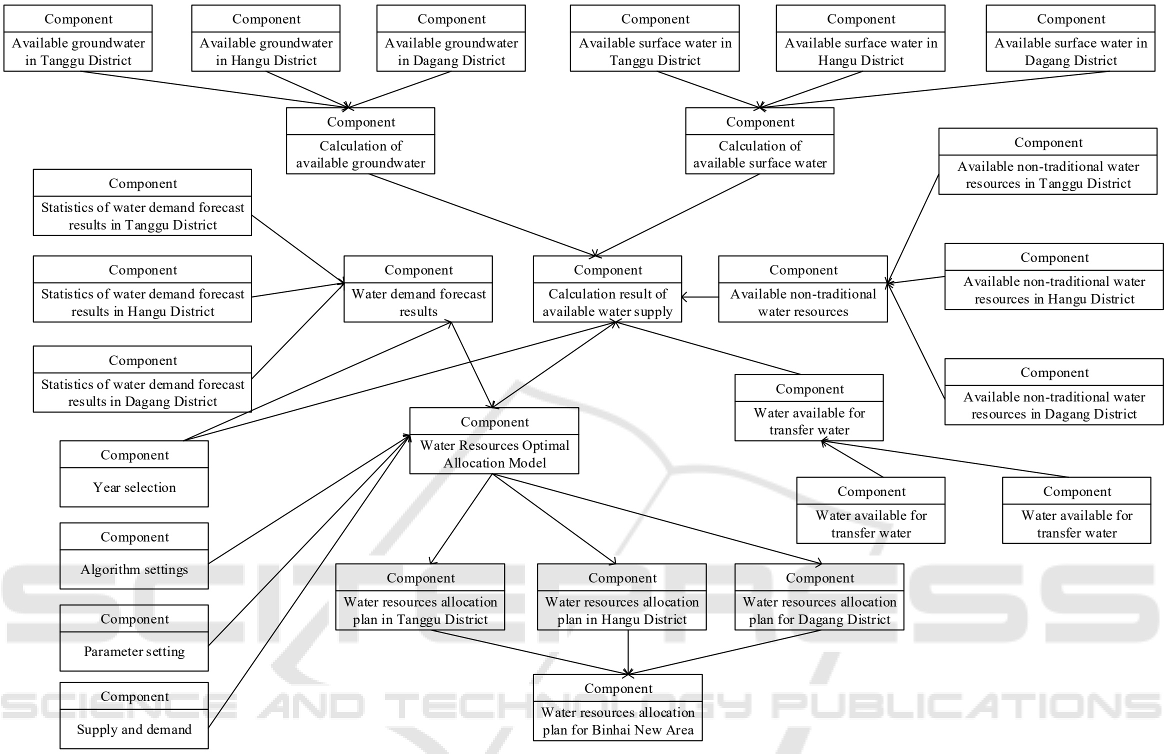

Figure 1: Regional water resources configuration components.

3 REALIZATION OF REGIONAL WATER RESOURCES ALLOCATION MODEL

3.1 Technical Support for Model Implementation

3.1.1 Knowledge Visualization Integration Platform

Integrated platform based on SL538-2011 technical standards for design, overall architecture includes support layer, resource layer, information integrated the four levels of layer and user layer, implemented including discussion support environment, the human-computer interaction interface, knowledge processing and management, report generation and management decision-making, communication and transmission management, system maintenance, etc. In addition, the platform makes the model method componentized. By using components, Web services and other technologies, each link of business application can be realized by developing and encapsulating components. When there are new requirements or businesses, convenient and rapid modifications can be made, and the required model can be flexibly built to realize timely update of services.

3.1.2 Component Development Technology

Component is a unit of software with complete semantics, correct syntax, and reusable value. It is a system that can be clearly identified in the process of software reuse. Structurally, it is a complex of semantic description, generic interface, and implementation code (Luo, 2009). A water component is a simple encapsulation of water data and water methods. It can have its own properties and methods. Properties are simple visitors to the component data, and methods are some simple and visible functions of the component. The purpose of the design of water conservancy components is to provide information services for the construction of water conservancy applications on the comprehensive integrated platform and provide strong support for the expansion of water conservancy business applications (Mao, 2009).

3.1.3 Knowledge Visualization Technology

Visualization is the use of computer graphics and image processing technology, data into graphics or images displayed on the screen, and interactive processing theory, method and technology. The application of visualization technology in various fields not only makes each process visually visible and easy to understand, but also greatly improves the work efficiency of various industries (Li et al., 2011).

3.2 Water Resources Allocation Component Division

In order to realize the allocation of water resources, it is necessary to forecast the water demand, calculate the available water supply, establish the allocation model, write the algorithm, set the parameters and other steps to get the allocation scheme. Each step is coded by computer and implemented in the form of components. The components are logically divided according to the calculation process, as shown in Figure 1.

3.3 Water Resources Allocation Components and Systems

Optimization allocation of water resources for the allocation of water resources, for the area calculation according to the section on the division of components, optimized allocation of water resources need to be work mainly includes the water requirement of each area, regional supply amount calculation, model structures and parameters setting, based on the coupling relationship of components and system function, the component is added to the mapping relations with the node, Each node of the digital water network has its corresponding data or description, which realizes the function of water resources optimization configuration at the business level.

4 MODEL APPLICATION

4.1 Research Area Overview

In this paper, the representative Binhai New Area of Tianjin is selected as the research area. Binhai New Area is named for its proximity to the Bohai Sea and is located in the east of the center of Tianjin. The land area is more than 2,000km^2, the sea area is nearly 3,000 km^2, and the coastline is as long as 153*km*. Tanggu, Hangu and Dagang are three administrative regions under its jurisdiction. It is one of the most economically and technologically developed regions in China and an important maritime gateway between north China and the rest of the world. Binhai New Area has a warm temperate subhumid continental monsoon climate, with an average annual precipitation of about 600*mm*, mainly in summer, up to 80% of the annual rainfall, and annual evaporation of 1469.1*mm*. All the rivers flowing into the sea of the Haihe River flow into the Bohai Sea through the Binhai New Area. The main rivers flowing through Binhai New Area include Chaobai New River, Ji Canal, Yongding New River, Dushu River, Haihe River, Ziya New River and other first-grade channels; There are 11 secondary river courses in Binhai New Area, with a length of 220*km*. There is one large reservoir, namely Beidagang reservoir, seven medium-sized reservoirs and 23 small reservoirs, with a total storage capacity of 732 million m^3. This paper mainly studies the allocation of non-traditional water resources in Binhai New Area, and sets 2015 as the current level year and 2030 as the planned level year.

4.2 Water Resources Allocation System Application

Figure 2 shows the interface of optimal allocation of water resources in Binhai New Area. The main water system map of Binhai New Area is summarized and various water sources are represented in the map. Click the icon of the reservoir to view the basic information of the reservoir. Click the groundwater icon to view the recoverable amount of groundwater in each sub-area; Click the icon of non-traditional water resources to view the availability of non-traditional water resources in each sub-region; Click the external water transfer icon to view the water supply of the corresponding water transfer project.

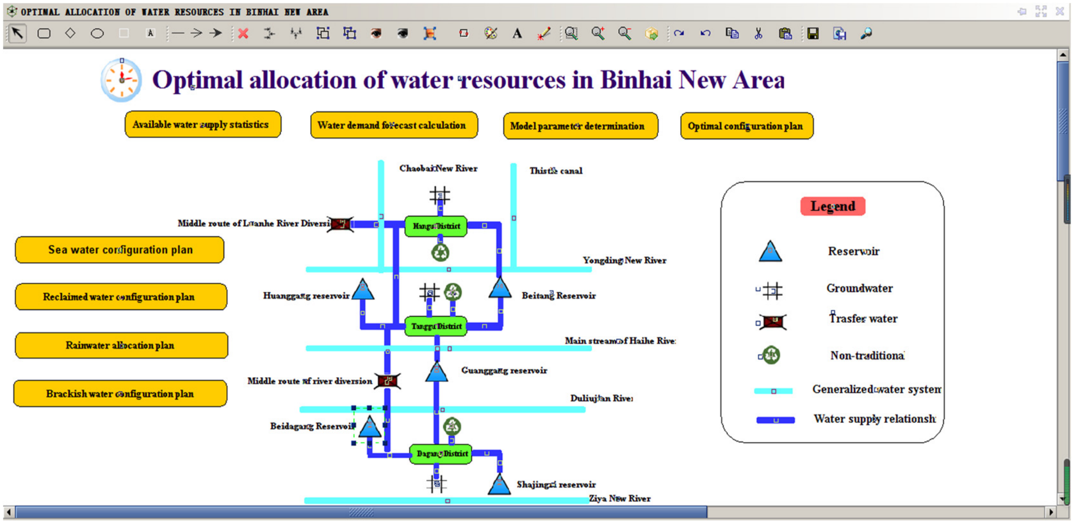

Figure 2: Water resources configuration interface of Binhai New Area.

Click the area name node of each district to enter the water resource configuration interface of the corresponding district. Figure 3 shows the screenshots of the water resource allocation system in each zone. The granularity of water resource allocation can be realized by the nesting of knowledge graph.

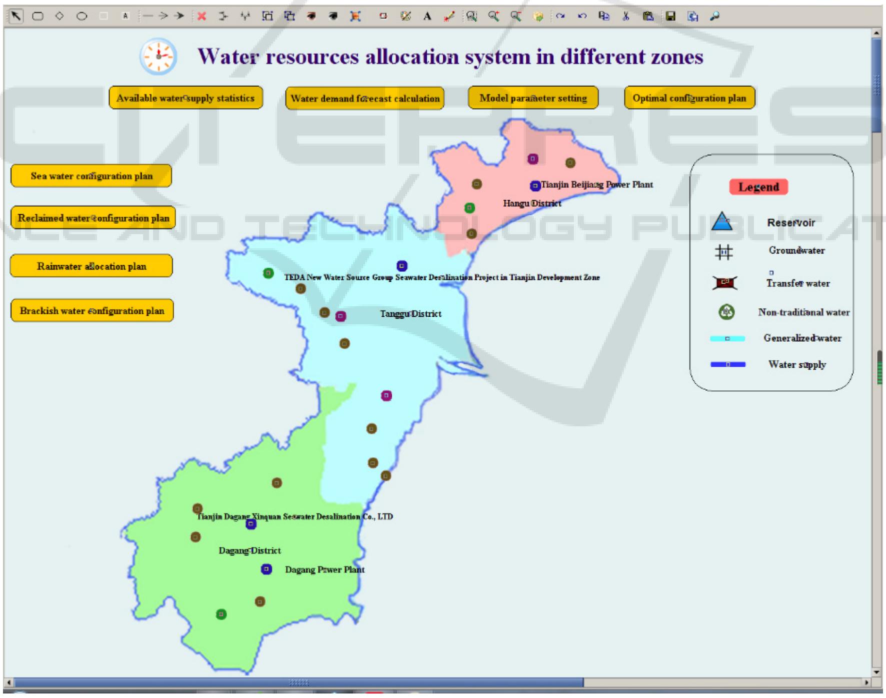

Figure 3: Water resources configuration page for a sub-region.

Click the parameter setting button to adjust the model parameters of the optimal configuration algorithm. In addition to the fact that some parameters linked to the local basic situation have been written into the components during programming, the weights of the three configuration objectives, the number of particle populations and the number of iterations need to be set.

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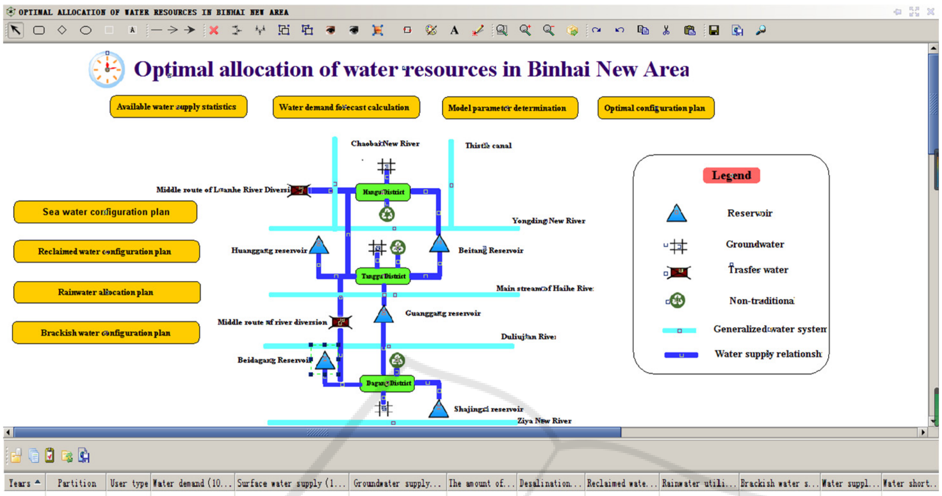
4.3 Overall Allocation of Water Resources in Binhai New Area

Click the clock button to select the horizontal year. Due to space limitation, this paper only shows the configuration results in 2030, as shown in Figure 4.

The configuration results show that the water supply in Binhai New Area can basically meet the demand, and the water shortage is mainly concentrated on ecological water. The main reasons are that the weight of ecological objectives in parameter setting is small and the local surface water is small, which mainly relies on external water diversion, which is mainly used for production and living.



Years	Partition	User type	Water demand (10...	Surface water supply (1...	Groundwater supply...	The amount of...	Desalination...	Reclaimed wate...	Rainwater utili...	Brackish water s...	Water suppl...	Water short...
2030	Tanggu Dis...	Life	0.82	0.12	0.1	0.02	0.2	0.08	0.22	0	0	0
2030	Tanggu Dis...	Ecology	0.92	0.08	0	0	0	0.69	0	0	0	0.13
2030	Tanggu Dis...	Production	3.56	0	0.1	2.49	0.6	0	0	0.37	0	0
2030	Hangu Dist...	Ecology	0.72	0.1	0	0	0	0.56	0	0	0	0.06
2030	Hangu Dist...	Life	0.56	0	0.04	0.26	0.16	0.06	0.04	0	0	0
2030	Hangu Dist...	Production	1.81	0	0.06	1.33	0.42	0	0	0	0	0
2030	Dagang Dis...	Ecology	0.71	0.1	0	0	0	0.43	0	0	0	0.18
2030	Dagang Dis...	Life	0.51	0	0.1	0.07	0.14	0.02	0.13	0	0	0.02
2030	Dagang Dis...	Production	2.94	0	0.1	0.77	0.56	0	0	0	0.63	0
2030	Binhai New...	Total	12.5	0.4	0.5	5.8	2.18	1.83	0.4	0.37	0.63	0.39

Figure 4: Water resources allocation in Binhai New Area in 2030.

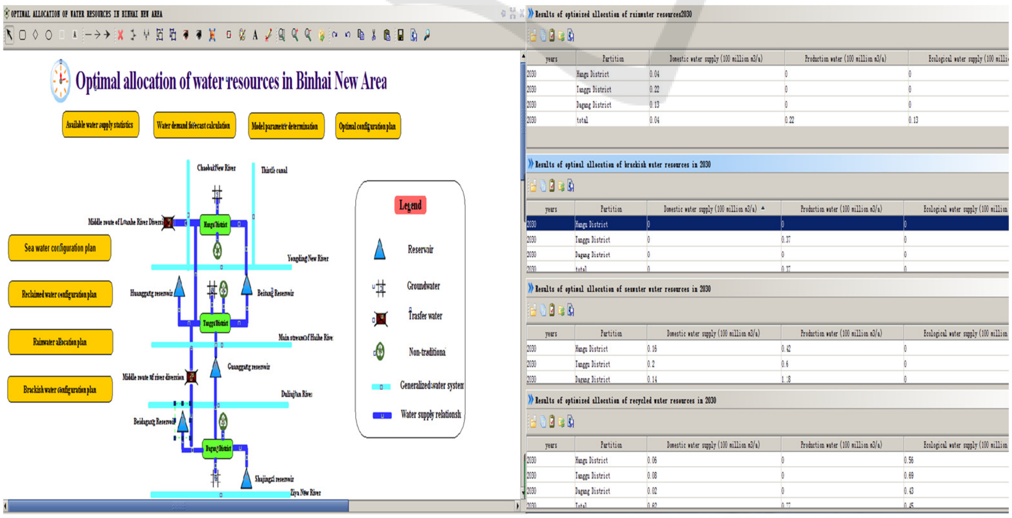


Figure 5: Results of non-traditional water resources allocation in Binhai New Area in 2030.

4.4 Results of Non-traditional Water Resources Allocation

Figure 5 shows the allocation of four types of non-traditional water resources in 2030. It can be seen from the configuration results that with the increase of rainwater resource utilization, the available water supply of domestic water increased significantly.

Through the analysis of the results of non-traditional water resources allocation, the availability of non-traditional water resources in Binhai New Area is increasing. As for the allocation of non-traditional water resources, the non-traditional water resources in each region are mainly allocated for local use, and there is no cross-regional allocation. Tanggu District has the most non-traditional water resources. Brackish water in Binhai New Area is used for production; Rainwater users for life; Sea water is used for living and production.

5 CONCLUSION

This paper mainly studies the model of incorporating non-traditional water resources into regional water resources allocation. The economy, society and ecology are taken as the objective functions of the allocation model, and the fitness function is selected to simplify the multi-objective problem into a single objective solution. The constraint conditions are determined, the decision variables are set, the regional water resource allocation model is constructed, and the allocation scheme is solved by particle swarm optimization algorithm. Through the componentization of water demand prediction, available water supply calculation, supply and demand balance calculation and configuration model, and the coupling of components and system functions, the optimal allocation system of water resources in Binhai New Area is established. To realize the rational allocation of regional non-traditional water resources, the research results provide a reference for considering the allocation of non-traditional water resources.

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