Study on Evaluation of Water Resources Carrying Capacity based on Supply and Demand Balance Analysis: Take Julu County, Hebei Province as an Example

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Abstract: The shortage of water resources is a rigid constraint factor that limits the development of regional economy and society. The purpose of this study is to scientifically calculate the carrying capacity of water resources, taking into account factors such as natural endowment of resources & environment and pressure of social & economic development. Based on the analysis of supply and demand balance, the idea of water resources carrying capacity calculation based on supply-demand balance analysis is constructed, which includes four steps: "resource endowment analysis - pressure state analysis - supply - demand balance analysis - carrying capacity calculation". Taking Julu County of Hebei Province as a case, based on the calculation of water resources supply and demand, and the analysis of supply and demand balance under multi-scenario simulation, the water resources carrying capacity is comprehensively calculated. The results show that, considering precipitation and surface runoff, exploitable groundwater, regional water transfer and reclaimed water reuse projects, the total available water resources at the end of the planning period are 89.11 million m3. After comprehensively popularizing agricultural water-saving irrigation, ensuring domestic water consumption of urban and rural residents and optimizing the water-saving industrial structure, the total water resources demand at the end of the planning period is 76.74 million m3. Through the analysis of the balance between supply and demand, the water resources structure optimization scheme is formed, and the comprehensive carrying capacity of water resources is calculated, including 420,700 urban population, 173,000 rural population, 32,700 hectares of cultivated land, 4,474 hectares of urban construction land, 3,453 hectares of village construction land and 2,401 hectares of industrial land, thus realizing the rigid constraint goal of "determining city, land, people and production by water".

1 INTRODUCT

1.1 Background

Resources and environment are the material basis of economic and social development and the basic carrier of economic development. At the same time, the changes in the structure and state of resources and environment seriously restrict the speed of economic development (Liu et al., 2020). In terms of carrying capacity of resources and environment, social and economic development is generally restricted by water and soil. More than 80% of the carrying capacity of urban agriculture and urban construction in China is restricted by water, especially in water-deficient cities such as Ningxia and Hebei provinces (Song et al., in press). With the rapid development of economy and society in the future, urban water demand is increasing rigidly, and water resources is facing a more severe situation.

The Decision of the Central Committee of the Communist Party of China on Several Major Issues Concerning Comprehensively Deepening Reform at the Third Plenary Session of the 18th CPC Central Committee put forward that "a monitoring and early warning mechanism for carrying capacity of resources and environment should be established, and restrictive measures should be taken for areas with water and soil resources overload, environmental capacity and marine resources" (Wang et al., 2020). In 2014, 2019 and 2020, General Secretary Xi Jinping put forward that water resources should be regarded as the biggest rigid constraint in development, and it is necessary to insist on determining city, land, population and industry by water, taking water resources as the

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biggest rigid constraint and rationally planning the development of population, city and industry (Song et al., 2020). General Secretary Xi Jinping particularly emphasized that when planning land space and regional economic layout, it was necessary to implement the strategy of main functional areas, scientifically plan the protection pattern of land space development and effectively standardize the order of space development on the basis of the carrying capacity of resources and environment and the suitability evaluation of land space development.

1.2 Research Reviews

The carrying capacity of water resources refers to the water resources in a certain area. It's the largest agricultural, industrial, urban scale and population that can be carried. This ability is a comprehensive goal that changes with the development of economy and society. Foreign studies on water resources carrying capacity mainly focus on urban water supply and agricultural production (Li et al., 2020). In China, the research on water resources carrying capacity began in the late 1980s. In 1989, Xinjiang Water Resources Soft Science Research Group put forward the concept and evaluation model of water resources carrying capacity, and adopted the conventional trend method to study the water resources carrying capacity of Urumqi River Basin in Xinjiang (Tang et al., 2021). At present, the main evaluation methods of water resources carrying capacity include empirical formula method, comprehensive evaluation method and system dynamics method (Du et al., 2020). Among them, the empirical formula method is a formula derived and summarized by the dimensional principles, which come from production practice. Its advantage is simple calculation and easy popularization and application, but less consideration is given to the connection between resources and economy and society. The basic idea of comprehensive evaluation method is to calculate through the selected indicators and evaluation standards, and then comprehensively evaluate the bearing capacity according to the calculated values. The disadvantages are that it is difficult to unify the selection of indicators and determine the evaluation standards. The system analysis method mainly adopts the system dynamic model, optimization model and control target inversion model, etc., which has the advantage of considering the complexity and systematisms of "economic society - water resources - ecological environment", but the deficiency is that the calculation method is complex, the process is cumbersome and difficult to popularize and apply (Zhang et al., 2019).

In a word, the influencing factors of water resources carrying capacity include social development, resource endowment, supporting status and environmental protection, which are comprehensive reflection of the balance between supply and demand of water resources (Zhang et al., 2020). Bearing capacity can be understood as a system consisting of four elements: bearing support, bearing pressure, action relationship and elastic result. Some studies have built up "Pressure state response" models to calculate the resources carrying capacities (Niu et al., 2020). Bearing support has the characteristics of objectivity and structure, while bearing pressure has the characteristics of initiative and relativity. The action relationship is restricted by the action mechanism of subject and object, and bearing capacity is influenced by social values, which is an elastic result (Ma et al., 2020).

1.3 Research Approach

This paper constructs an idea of water resources carrying capacity calculation based on supply-demand balance analysis (Figure 1), which includes four steps: "resource endowment analysis-pressure state analysis-supply demand balance analysis-carrying capacity calculation". Based on the calculation of water supply and demand, and the supply-demand balance analysis under multi-scenario simulation, the optimization scheme of water resources utilization structure is obtained, according to "determining city by water, land by water, population by water, and industry by water".

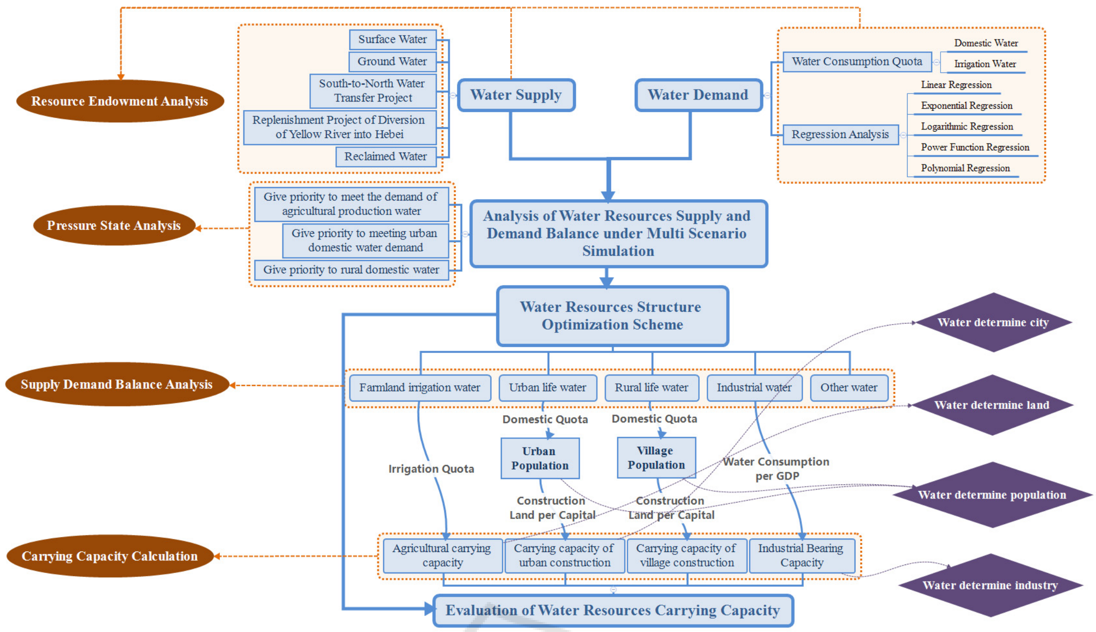

Figure 1: Approach of calculating water resources carrying capacity.

2 WATER RESOURCE ENDOWMENT ANALYSIS

2.1 Surface Water

According to the spatial distribution results of surface water in each township in Julu County Water Resources Evaluation Report (Table 1), the annual runoff under the guarantee rate of 50% in Julu County Water Resources Overall Utilization and Protection Plan is 1,158,600 m^3. According to the utilization rate of surface water: the surface runoff under the guaranteed rate of 50%, the utilization rate of surface water is 0.68; Under the guarantee rate of 75%, the utilization rate of surface water is 0.87. The formula: surface water = annual runoff × surface water utilization rate can be calculated, and when the guarantee rate is 50%, the available surface water in Julu County is 790,000 m^3.

Table 1: Distribution of surface water resources in Julu County.

Administrative divisions	Average value		Parameter		Annual runoff at different frequencies (10,000 m3)			
	Runoff depth	Runoff volume	Cv	Cs/Cv	20%	50%	75%	95%
Julu	6.2	54.83	1.65	2	75.11	15.9	2.03	0
Xiguocheng	7.6	23.87	1.65	2	32.7	6.92	0.88	0
Guanting	6.1	44	1.65	2	60.28	12.76	1.63	0
Yantuan	6	40.33	1.65	2	55.25	11.7	1.49	0
Xiaolvzhai	7.2	25.64	1.65	2	35.13	7.44	0.95	0
Wanghuzhai	6.9	26.46	1.65	2	36.26	7.67	0.98	0
Zhangwangtuan	5.9	48.88	1.65	2	66.96	14.17	1.81	0
Sujiaying	5.8	46.79	1.65	2	64.1	13.57	1.73	0
Dicun	6	46.34	1.65	2	63.49	13.44	1.71	0
Guanzhai	6.2	37.1	1.65	2	50.83	10.76	1.37	0
County	6.3	399.5	1.65	2	547.32	115.86	14.78	0

References: Julu County Water Resources Evaluation Report

2.2 Ground Water

Combined with the spatial distribution results of groundwater in Julu County Water Resources Evaluation Report and groundwater prediction results in Julu County Water Resources Overall Utilization and Protection Plan, the total available groundwater resources in Julu County is 34,330,000 m^3. Julu County is a saline water area, and deep groundwater has been developed and utilized. According to the actual situation, considering the conditions of not causing ground subsidence and upper saltwater infiltration downward, the annual allowable exploitation amount under the limited head drop value is determined. From 1991 to 2005, the annual average over-flow recharge of shallow water to deep groundwater was 19,115,000 m^3, the annual average lateral recharge of deep water was 2,354,300 m^3, and the annual average lateral outflow of deep water was 1,883,400 m^3, so the annual allowable exploitation of deep groundwater in Julu County was 19,585,900 m^3.

2.3 South-to-North Water Transfer Project

The "South-to-North Water Transfer Project" is a strategic project of the People's Republic of China, which is divided into three routes: east, middle and west. The starting point of the eastern route project is located at Jiangdu Water Control Project in Yangzhou, Jiangsu Province. The starting point of the middle line project is located in Danjiangkou Reservoir in the middle and upper reaches of Hanjiang River, and the water supply areas are Henan, Hebei, Beijing and Tianjin.

The South-to-North Water Transfer Project in Xingtai City is an important infrastructure to solve the serious shortage of water resources, realize the optimal allocation of water resources, ensure the safety of water supply in county towns, and improve the agricultural production conditions and ecological environment. Besides huge economic benefits, it also has extensive social benefits. It is a strategic project with dual functions of public welfare and management. The direct water supply targets of the South-to-North Water Transfer Project are cities (including county towns and key industrial areas) and industries. The overall water shortage situation in the water receiving area can be improved by returning water to agriculture, limiting the exploitation of groundwater and making full use of the increased backwater in cities.

According to the Master Plan of South-to-North Water Transfer Project, the average annual water transfer amount of the first phase of the Middle Route Project is 9,500,000,000 m^3, with 3,500,000,000 m^3 in Hebei Province. According to "Opinions on Water Distribution and Scale Adjustment of Supporting Projects in Hebei Province in the Middle Route of South-to-North Water Transfer Project", the water quantity in Xingtai City is 333,350,000m^3, and combined with the secondary supply and demand analysis results of "Water Resources Planning of South-to-North Water Transfer Project in Xingtai City, Hebei Province", the target water supply quantity in Julu County is 5,970,000 m^3, which is mainly used for urban domestic water and industrial water.

2.4 Replenishment Project of Diversion of Yellow River into Hebei

In the water diversion project from the Yellow River to Hebei Province, the water conveyance line draws water from the gate of Huanghequ Village in Henan Province, uses Puqing South Main Canal in Puyang City, and passes through Weihe River to enter Hebei Province. In Hebei Province, the existing canals are basically used to deliver water, passing through Dongfeng Canal, Laozhang River and Jiaodongpai River to xian county Hub, passing through Hutuo River North Dike, and then using Zita Main Canal, Guyanghe River, Xiaobai River and Renwen Main Canal to deliver water to Baiyangdian Lake.

After the South-to-North Water Transfer Project is fully supplied, the index of water diversion from the Yellow River in Hebei Province is 620,000,000m^3, and the water diversion time is April in winter. The designed discharge at the head of the project is 150 m^3/s, of which the designed discharge at the water receiving area in Hebei Province is 61.4m^3/s. The water transfer line from the Yellow River to Hebei passes through 10 counties in Xingtai, and the amount of water allocated to Julu County is 18,550,000m^3.

2.5 Reclaimed Water

To solve and alleviate the increase of water resources demand and the aggravation of water pollution caused by urbanization, it is necessary to improve the efficiency of water resources recycling. The recycling of urban water resources is conducive to reducing the demand for freshwater resources and alleviating the water supply pressure of urban water resources (Zeng et al., 2021). According to the industrial development and residents' living water level in Julu County, using industrial water, urban public service and urban living water to calculate the sewage discharge, the recovery rate is 80%, the loss in the treatment process is 10%, and the utilization rate of treated reclaimed water is 80%. The reclaimed water reuse amount is about 9,880,000 m^3.

2.6 Total Water Resources Supply

To sum up, the total amount of available water resources in Julu County by 2025 and 2035 is shown in Table 2.

Table 2: Total available water resources in Julu County in 2025 and 2035.

Unit: 10,000 m3

Planning period	Total	Surface water	Ground water	South-to-north water diversion	Diverting water from the Yellow River into the main canal of Hebei Province	Reclaimed water
2025	8531	78	5392	597	1855	608
2035	8911	78	5392	597	1855	988

3 WATER RESOURCE PRESSURE STATE ANALYSIS

Linear and non-linear regression analysis methods are used to predict the production and domestic water consumption and structure in the planning period by fitting historical data. However, the regression analysis method is only an objective mathematical statistical analysis method based on history, and the regression model should be optimized in combination with social and economic development and water saving measures.

3.1 Farmland Irrigation

According to the total water resources minus the current (2018) water consumption for forestry, animal husbandry, fishery and livestock, urban public, ecological environment, residents' living and industrial water, the theoretical maximum scale of farmland irrigation water can be calculated, which will be 69,291,800 m^3 and 73,091,800 m^3 by 2025 and 2035 respectively.

Using the regression analysis results (Table 3), the polynomial regression fitting effect is the best, which is mainly due to the farmland irrigation water after a continuous decline during 2014-2017, and a small increase in 2018, so from the model point of view, it is more in line with the change trend of the polynomial model. But in fact, the irrigation water consumption of Julu County will continue to decline with the increase of water-saving irrigation area, adjustment of crop planting structure and irrigation mode, promotion of Double Ridge Film Mulching and furrow sowing technology. In addition, the results of linear regression and exponential regression obviously do not conform to the actual situation, so the power function regression equation is used to predict.

Table 3: Regression analysis results of farmland irrigation water.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-487.21x+8039.4	0.5595	1705.67	-2679.22
Exponential regression	$y=8036.2e^{-0.07x}$	0.5378	3469.31	1722.81
Logarithmic regression	y=-1404ln(x)+7922.3	0.7509	6407.13	6037.54
Power function regression	$y=7904.3x^{-0.202}$	0.7235	4784.86	4233.45
Polynomial regression	y=357.87x2-2634.4x+10544	0.9821	30464.48	125796.28

3.2 Water Consumption for Forestry, Animal Husbandry, Fishery and Livestock

The continuous decline of water consumption during 2014-2018, the fitting effect of various regression methods is good, and the difference is not big (Table 4). From R^2, the highest is logarithmic regression, that is, the quantity of forestry, animal husbandry, fishery and animal husbandry will continue to decline, but the decline rate will gradually slowdown, which is more in line with the relevant forestry and fruit industry and animal husbandry development plan of Julu County, so logarithmic regression equation is used for prediction.

Table 4: Regression analysis results of water use for forestry, animal husbandry, fishery and livestock.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-103.73x+1363.7	0.8433	15.21	-918.36
Exponential regression	$y=1396.6e^{-0.098x}$	0.8579	430.87	161.71
Logarithmic regression	y=-265.2ln(x)+1306.5	0.8908	1020.30	950.49
Power function regression	$y=1316.4x^{-0.245}$	0.8690	716.12	617.30
Polynomial regression	y=12.461x2-178.5x+1450.9	0.8604	1103.28	3555.02

3.3 Industrial Water Consumption

From the model fitting results (Table 5), the polynomial regression is the best, but the prediction result in 2035 is extremely high, which does not conform to the actual situation. Considering the development target of annual industrial added value and the promotion of industrial water-saving measures in Julu County, the prediction result of polynomial regression in 2025 is taken as the maximum value of industrial water consumption.

Table 5: Regression analysis results of industrial water.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-8.538x+181.54	0.3533	70.55	-6.30
Exponential regression	$y=180.12e^{-0.051x}$	0.3137	97.67	58.65
Logarithmic regression	y=-26.61ln(x)+181.41	0.5546	152.69	145.69
Power function regression	$y=180.33x^{-0.161}$	0.5053	120.87	109.63
Polynomial regression	y=9.2414x2-63.987x+246.23	0.9328	809.15	3311.35

3.4 Prediction of Urban Public Water Use

In recent years, the urban public water consumption also showed a trend of continuous decline and then a small increase, making the polynomial regression fitting effect the best, but the urban public water consumption will not show a trend of high-speed exponential growth in the future, and the gradual completion of urban public service facilities, water demand will show an upward trend (Table 6). Therefore, the logarithmic regression equation is used for prediction.

Table 6: Regression analysis results of urban public water use.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-28.4x+213	0.6126	-156.20	-411.80
Exponential regression	$y=212.29e^{-0.19x}$	0.6532	21.71	3.25
Logarithmic regression	y=-81.52ln(x)+205.86	0.8154	117.89	96.43
Power function regression	$y=201.1x^{-0.539}$	0.8486	52.69	38.01
Polynomial regression	y=17.571x2-133.83x+336	0.9409	1260.26	5896.10

3.5 Urban Domestic Water

According to the total amount of water resources minus the current situation (2018) of farmland irrigation, forestry, animal husbandry, fishery and livestock, urban public, ecological environment and industrial water, the maximum theoretical scale of urban domestic water can be calculated according to the current urbanization rate and per capita domestic water quota, which will be 4,073,600 m^3 and 5,656,400 m^3 by 2025 and 2035 respectively.

Although from the model fitting effect (Table 7), the polynomial regression fitting effect is the best, and it can ensure the residents' domestic water consumption to the maximum extent, but the forecast value in 2035 is too divorced from the reality. According to the prediction of per capita urban domestic water consumption from 2014 to 2018, and the resident population, the per capita urban water consumption is maintained at about 20 m^3/ day in 2014, except for 34 m^3/ day in 2014. However, the minimum value of domestic water consumption per capita in Hebei Province is also 50 m^3/ day. Even if the urban population scale remains unchanged, the urban domestic water consumption also needs to be greatly increased. Therefore, the polynomial regression model is used to predict the urban living water consumption in 2025 to ensure the basic living needs of the people. However, in the 10 years from 2025 to 2035, the average annual growth of urban domestic water is basically the same as that in 2018-2025, and the urban domestic water will be about 9,820,000 m^3 by 2035.

Table 7: Regression analysis results of urban domestic water.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-8.2x+133.4	0.5946	26.80	-47.00
Exponential regression	$y=133.12e^{-0.07x}$	0.5994	57.47	28.54
Logarithmic regression	y=-23.69ln(x)+131.48	0.8018	105.91	99.68
Power function regression	$y=130.9x^{-0.202}$	0.8047	79.24	70.11
Polynomial regression	y=5.4286x2-40.771x+171.4	0.9595	463.87	1901.88

3.6 Rural Domestic Water

Similar to the calculation process of the maximum theoretical scale of urban domestic water, the maximum theoretical scale of rural domestic water can be calculated, which will be 5,706,400 m^3 and 7,923,600 m^3 by 2025 and 2035 respectively.

According to various models (Table 8), the fitting effect is not ideal. From 2014 to 2018, the per capita rural domestic water consumption increased continuously from 29.49 m^3/day to 32.64 m^3/day according to the permanent population. However, there is still a big gap from the minimum standard of water quota in Hebei Province. If only from the perspective of ensuring the basic domestic water demand of the people, the rural domestic water consumption needs to reach 1.53 times (50 / 32.64) of the current situation, and the annual water consumption can reach about 4,610,000 m^3. However, considering that the urbanization process of rural population will continue in the planning period, the predicted value is taken as the maximum value of rural domestic water.

Table 8: Regression analysis results of rural domestic water.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=0.502x+298.69	0.0163	305.22	309.73
Exponential regression	$y=298.55e^{0.0018x}$	0.0187	305.07	310.61
Logarithmic regression	y=2.4792ln(x)+297.82	0.0643	300.50	301.15
Power function regression	$y=297.71x^{0.0085}$	0.0691	201.93	202.97
Polynomial regression	y=-1.2129x2-7.7791x+290.2	0.1497	208.89	-125.70

3.7 Water for Ecological Environment

The ecological environment water consumption includes urban environment and rural ecological water consumption. In recent years, the ecological environment water consumption in Julu County has continued to increase. According to the goal of ecological civilization construction, it can be predicted that the water demand for ecological environment will continue to increase in the planning period. However, Julu County is a water shortage area, and the limited water resources should first meet the needs of people's life, so the power function regression equation is used to predict (Table 9).

Table 9: Regression analysis results of ecological environment water use.

	Regression equation	R^2	Forecast value in 2025 (10,000 m^3)	Forecast in 2035 (10,000 m^3)
Linear regression	y=-7.06x+80.58	0.8848	172.36	235.90
Exponential regression	$y=82.439e^{0.0684x}$	0.8909	187.33	371.24
Logarithmic regression	y=16.022ln(x)+86.419	0.7363	103.71	107.93
Power function regression	$y=87.178x^{0.156}$	0.7482	128.46	141.20
Polynomial regression	y=1.4429x2-1.5971x+90.68	0.9366	279.29	753.91

3.8 Total Water Demand

In conclusion, based on historical data, socio-economic development trend and water-saving measures, the total production and domestic water consumption in Julu County will be 77,860,000 m^3 and 76,740,000 m^3 by 2025 and 2035 respectively, which is less than the total amount of available water resources in the county. This result will be an important basis for water structure optimization (Table 10).

Table 10: Forecast summary of production and domestic water in Julu County.

Unit: 10,000 m^3

Planning period	Farmland irrigation	Forestry, animal husbandry, fishery and livestock	Industry	Urban public	Urban life	Rural life	Ecological environment
2025	4784.86	1020.30	809.15	117.89	463.87	461.00	128.46
2035	4233.45	950.49	809.15	96.43	982.25	461.00	141.20

4 ANALYSIS OF WATER RESOURCES SUPPLY AND DEMAND BALANCE UNDER MULTI SCENARIO SIMULATION

Planning water consumption structure is an important basis for the calculation of water resources carrying capacity. Since the water demand for production and living is less than the available water resources, the water consumption for production and living should be fully allocated from the perspective of supply. In this process, it is necessary to consider the water consumption, water resources allocation of the south to North Water Diversion Project and other factors, as well as the current situation and development trend of water use structure, so as to simulate the water use structure under different development goals.

4.1 Give Priority to Meet the Demand of Agricultural Production Water (Scheme I)

Firstly, according to the prediction results of urban and rural domestic water in the previous chapter, the urban and rural domestic water is considered. Secondly, the demand forecast results are also adopted for the water consumption of forestry, animal husbandry, fishery and livestock, urban public and ecological environment. Thirdly, as agricultural production is given priority in this scheme, the industrial water consumption is appropriately reduced.

Based on considering the basic water demand of urban, rural, and industrial areas, the South-to-North Water Diversion Project is mainly used for urban life, and the remaining water resources is calculated under the target of agricultural water use (Table 11).

Table 11: Water structure of Julu County in the planning period (scheme I).

Unit: 10,000 m^3

Planning period	Farmland irrigation	Urban life	Rural life	Industrial water	Other water
2025	5553.8	993.7	158.68	476.04	1348.78
2035	5653.52	1012.7	166.28	665.12	1413.38

4.2 Give Priority to Meeting Urban Domestic Water Demand (Scheme II)

Different from the first scheme, the agricultural irrigation water demand is determined firstly, and the industrial water consumption will be increased to a certain extent by giving priority to urban domestic water. However, the industrial water consumption in this scheme does not exceed the maximum value. Considering the medium water generated by the increase of urban domestic and industrial water can be used for urban environment, other water consumption in this scheme is also increased based on demand. Similarly, considering the feasibility of water-saving measures, the agricultural irrigation demand is predicted to rise by about 10% in the previous chapters.

Based on considering the basic water demand of agriculture and rural areas, the proportion of industrial water and ecological water is moderately increased under the premise that the water transferred from south to north is mainly used for urban life, and the remaining water resources are all classified as urban domestic water. The water consumption in this method is also adjusted along with the industrial water consumption in cities and towns (Table 12).

Table 12: Water consumption structure of Julu County in planning period (Scheme II).

Unit: 10,000 m^3

Planning period	Farmland irrigation	Urban life	Rural life	Industrial water	Other water
2025	5496.52	1009.38	247.43	577.33	1649.52
2035	4791.51	1365.20	256.07	768.20	2048.54

4.3 Give Priority to Rural Domestic Water (Scheme III)

Different from the former two schemes, this scheme does not take urban life as the only purpose of the south to North Water Diversion Project, but puts it into the overall consideration of the total water resources. Moreover, the rural domestic water consumption is close to the limit value of rural domestic demand, and the urban domestic water consumption will be reduced accordingly. Different from urban residents, rural villagers will still take agriculture, fruit, animal husbandry and other industries as the main employment areas, so the production water consumption will also increase.

Based on the consideration of the basic water demand of urban life, rural life and industry, this scheme is calculated under the goal of classifying all the remaining water resources as agricultural water use (Table 13).

Table 13: Water consumption structure of Julu County in planning period (Scheme III).

Unit: 10,000 m^3

Planning period	Farmland irrigation	Urban life	Rural life	Industrial water	Other water
2025	5374.53	511.86	426.55	511.86	1706.20
2035	4901.05	891.10	445.55	712.88	1960.42

4.4 Water Resources Structure Optimization Scheme (Recommended Scheme)

Based on the above three schemes, the South-to-North Water Diversion Project is still mainly used for urban life, and the water consumption of all walks of life is coordinated on the basis of comprehensive consideration of basic demand and the highest scheme (Table 14).

Table 14: Water structure of Julu County in the planning period (Recommended Scheme).

Unit: 10,000 m^3

Planning period	Farmland irrigation	Urban life	Rural life	Industrial water	Other water
2025	5248.62	879.62	444.11	484.49	1614.96
2035	5052.24	1228.53	378.92	673.63	1684.08

5 WATER RESOURCES CARRYING CAPACITY CALCULATION

5.1 Agricultural Carrying Capacity

According to the above calculation results, the maximum theoretical scale of farmland irrigation will be 69,291,800 m^3 and 73,091,800 m^3 by 2025 and 2035 respectively. According to the scheme of giving priority to agricultural production water, the total amount of agricultural irrigation water will be 55,540,000 m^3 and 56,540,000 m^3 by 2025 and 2035 respectively. The calculation of water resources structure optimization scheme will be carried out, by 2025 and 2035, the total amount of agricultural irrigation water will be 52,486,200 m^3 and 50,522,400 m^3 respectively.

According to the provisions of water consumption quota for agriculture in Hebei Province (DB 13 / T 1161.1-2016), the representative crops in Julu County are corn, wheat, cotton and barbarum. Considering the different planting structure, multiple cropping situation, irrigation method and effective utilization coefficient of farmland irrigation water, the irrigation quota of Julu County is determined to be 1545 m^3 / hectares (Table 15).

Table 15: Planting Area.

Unit: hectares

Particular year	Corn	Wheat	Cotton	Wolfberry	Honeysuckle
2010	12678	16156	12964		
2011	12647	16011	13321	3988	5200
2012	12776	16067	12869	3921	5207
2013	12743	16347	12777	3812	5135
2014	13931	16153	11735		
2015	15325	16002	10053	3748	5111
2016	16885	18794	9019	3666	5158
2017	20084	18244	7760		
2018	22134	21708	359		
2019	18875	18225	351		

Reference: Statistical Yearbook of National Economic and Social Development in Julu County (2010-2020)

According to the formula, the bearable irrigation area = irrigation available water × farmland comprehensive irrigation quota, the maximum theoretical scale of bearable cultivated land in Julu County is 44,849 hectares and 47,309 hectares respectively. Under the situation of water resource constraint in 2025 and 2035, the bearable cultivated land area is 35,947 hectares and 36,593 hectares respectively. Under the situation of water resources structure optimization, the maximum theoretical scale of bearable cultivated land in Julu County is 44,849 hectares and 47,309 hectares respectively, by 2025 and 2035. The carrying area of cultivated land will be 33,972 hectares and 32,701 hectares respectively.

5.2 Carrying Capacity of Urban Construction

According to the above calculation results, the maximum theoretical scale of urban domestic water will be 4,073,600 m^3 and 5,656,400 m^3 by 2025 and 2035 respectively. According to the calculation of the scheme to give priority to urban domestic water, the total amount of urban domestic water will be 10,093,800 m^3 and 13,652,000 m^3 by 2025 and 2035 respectively. The calculation of water resources structure optimization scheme will be carried out by 2025 and 2035, the total domestic water consumption will be 8,796,200 m^3 and 12,285,300 m^3 respectively.

According to the data of domestic water consumption and urban population of Julu County from 2011 to 2018, the average urban domestic water consumption per capita in recent five years is about 24 L / person · day. According to the water consumption quota of Hebei Province (DB 13 / T 1161.1-2016), the values of 50, 80, 110 or 140 can be taken according to whether there are drainage, sanitary facilities and shower facilities in the room. To sum up, 50 and 80 are determined as the values of two domestic water consumption schemes, i.e. the per capita domestic water consumption is 18 m^3 / year and 29 m^3 / year.

According to the calculation formula, the carrying urban population = urban domestic water / per capita urban domestic water consumption, the bearable urban construction area = bearable population × per capita urban construction land. According to the per capita urban construction land index 106.35m^2 determined by Xingtai City, the maximum theoretical scale of urban construction land in Julu County is 1,484 hectares and 2,060 hectares respectively. Under the situation of giving priority to urban domestic water use, the carrying capacity of urban construction land in 2025 and 2035 will be 3,676 hectares and 4,972 hectares respectively. In the context of water resource’s structure optimization, the carrying capacity of urban construction land will be 3,204 hectares and 4,474 hectares by 2025 and 2035 respectively.

5.3 Carrying Capacity of Village Construction

According to the above calculation results, the maximum theoretical scale of rural domestic water will be 5,706,400 m^3 and 7,923,600 m^3 by 2025 and 2035 respectively. According to the scheme of giving priority to agricultural and rural domestic water, the total amount of rural domestic water will be 4,270,000 m^3 and 4,460,000 m^3 by 2025 and 2035 respectively. The calculation of water resource’s structure optimization scheme will be carried out by 2025 and 2035, the total amount of rural domestic water will be 4,441,100 m^3 and 3,789,200 m^3 respectively.

According to the domestic water consumption and resident population data of Julu County from 2014 to 2018, the average domestic water consumption per capita in recent five years is about 32 L / person · day. According to the water consumption quota of Hebei Province (DB 13 / T 1161.1-2016), the values of 50, 80, 110 or 140 can be taken according to whether there are drainage, sanitary facilities and shower facilities in the room. To sum up, 60 is determined as the value of rural domestic water consumption scheme, that is, the rural domestic water consumption per capita is about 22 m^3 / year.

According to the calculation formula, the carrying rural population = rural domestic water consumption / per capita rural domestic water consumption, and the bearing village construction area = bearable population × per capita village construction land. According to the per capita village construction land of 199.58m^2, the maximum theoretical scale of village construction land in Julu County is 5,201 hectares and 7,221 hectares respectively. The results show that the village construction land scale of Julu County in 2025 and 2035 is 3,887 hectares and 4,060 hectares respectively. In the context of water resources structure optimization, the village construction land scale in 2025 and 2035 will be 4,047 hectares and 3,453 hectares respectively.

5.4 Industrial Bearing Capacity

It is estimated that by 2025 and 2035, the industrial water consumption will be 4,844,900 m^3 and 6,736,300 m^3, accounting for 6% and 8% of the total water supply.

In recent 4 years, the average water consumption per 10,000 RMB of industrial added value is 9.32 m^3 / 10,000 RMB. According to Xingtai's water resources management system, after adopting water-saving facilities, the water consumption per 10,000

RMB of industrial added value in Julu County in the planning period is 9 m^3, the consumption per unit GDP is controlled below 50 m^2 /10,000 RMB, and the proportion of industrial land in urban construction land accounts for about 30%.

According to the calculation formula, the industrial bearing capacity = total industrial added value / per unit GDP water consumption (Xing et al., 2019). The industrial added value that Julu County carried in 2025 and 2035 are 5,383,000,000 RMB and 7,485,000,000 RMB respectively. Besides urban construction land, the scale of industrial land that can be carried is 1,731 hectares and 2,401 hectares respectively.

5.5 Comprehensive Carrying Capacity of Water Resources

Based on the optimization scheme of water resource's structure calculated in previous chapters, farmland irrigation quota, urban domestic water quota and rural domestic water quota, the comprehensive carrying capacity of water resources is calculated as follows (Table 16).

Table 16: Comprehensive Carrying Capacity of Water Resources in Julu County.

Unit: ten thousand people, hectares

Planning period	Cultivated land scale	Urban population	Rural population	Urban construction Land use	village construction Land use	Industrial land
2025	33971.65	30.12	20.28	3203.68	4047.32	1731
2035	32700.58	42.07	17.30	4474.46	3453.17	2401

6 COUNTERMEASURES

6.1 Vigorously Promote Water-Saving Irrigation Measures and Build a Water-Saving Agricultural Development Model

Strengthen the integration, assembly and matching of agronomy and farmland basic engineering technology, establish a technological innovation and service platform for dry farming water-saving agriculture, carry out original innovation, integrated innovation, introduction, digestion, absorption and re-innovation of dry farming water-saving agriculture technology, vigorously promote technological progress of dry farming water-saving agriculture, and improve the technical support system for the development of dry farming water-saving agriculture. Actively promote the application of subsoiling, increasing the application of organic fertilizer, straw returning and other mulching technologies, conservation tillage technology, promote water-saving and high-efficiency farming and cultivation mode, enhance soil water storage capacity, and reduce water consumption. Efforts will be made to improve the modern material and equipment level of drought resistance and water saving, improve the water delivery system, further strengthen the construction of low-pressure pipelines, water source projects and other facilities, and demonstrate and popularize water-saving modes such as drip irrigation under plastic film and irrigation and drainage of underground canals, so as to reduce water delivery losses and achieve water saving and efficiency improvement.

6.2 Promote the Adjustment of Industrial Structure and Relieve the Pressure of Water Resources System

Industry is usually the main source of pollution, and it is also one of the departments with a large consumption of water resources. In the case that agricultural irrigation water is difficult to be greatly reduced, industrial layout optimization has become an important starting point for industrial structure adjustment. Therefore, it is necessary to deeply analyze the consumption and demand of water resources in various industries, and evaluate the local water resources carrying capacity, water environment capacity and land resources carrying capacity under different industrial development modes, so as to determine the reasonable scale of industry and population.

6.3 Realize the Recycling of Water Resources and Effectively Improve the Supply and Utilization Efficiency

The recycling of urban water resources is closely related to natural environment, social environment and economic environment. It is necessary to manage regional water resources, water environment and water ecology, and rationally develop and utilize water resources. Advocate water conservation, vigorously promote water-saving appliances, and combine price management measures to appropriately increase water prices and reduce excessive use of domestic water. At the same time, we should take active measures to control the production water, encourage the recycling of water resources, improve the utilization rate of water resources, make full use of rainwater resources, expand available water sources and promote the recycling of urban water resources.

7 RESULTS AND DISCUSSIONS

The results show that the total available water resources at the end of the planning period in the case area is 89.11 million m, including surface water, groundwater, water transfer from the South-to-North Water Transfer Project and the Yellow River Diversion Project to Hebei, and reclaimed water reuse. Based on the results of linear and nonlinear regression analysis, considering the social and economic development goals and measures of saving and intensive water use, the total water demand at the end of the planning period of the case area is 76.74 million m^3. After simulating the balance scheme of water supply and demand in three scenarios, i.e. giving priority to agricultural production water, urban domestic water and rural domestic water, the optimal allocation scheme of water resources structure was formed, and then the comprehensive carrying capacity of water resources was calculated, including urban population of 420,700, rural population of 173,000, cultivated land of 32,700 hectares, urban construction land of 4,474 hectares, village construction land of 3,453 hectares and industrial land of 2,401 hectares.

The framework of water resources carrying capacity calculation based on the analysis of supply and demand balance, which is constructed in this paper, has achieved the rigid constraint goal of "determining city, land, people and output by water" through four steps: "resource endowment analysis-pressure state analysis-supply and demand balance analysis-carrying capacity calculation". However, this model has only been tried in some areas in the middle and south of Hebei Province. With the expansion of its application scope, the setting basis of various parameters, the comparison index of various models, balance analysis and structural optimization methods in this system need to be improved.

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