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Research Article

Analysis of Water Supply-Demand Based on Socioeconomic Efficiency

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Water resource is an important factor restricting social-economic development. Hebei Province is one of the regions suffering from severe water shortage in China. Based on the Water Resources Assessment and Planning model, population growth, economic growth, water-saving, and integrated scenarios were established. The water demand and supply in Hebei Province in 2025 and 2035 were forecasted in this study. The research results show that agriculture is the main unmet water demand sector. In the absence of large-scale population inflows, the local population growth has little impact on the changes in water supply-demand. Economic development is one of the main factors affecting water balance. The water-saving scenario has the greatest impact on water supply-demand. Compared to population and economic growth scenarios, the simulation results of water demand and unmet water demand were the smallest. Under an integrated scenario, the current situation of water shortage in Hebei has been greatly improved, but there is still a demand shortage of 44.12×10^8 m^3 in 2030. It is necessary to take measures to improve the carrying capacity of water resources in various regions of Hebei Province and narrow the regional gap. This study provided a reference for the rational utilization of water resources.

1. Introduction

Water is the source of all life. With the development of social economy, the available water resources are gradually decreasing globally [1–3]. Water scarcity has been listed as a major crisis of the 21st century [4, 5]. Globally, approximately 71% of the population suffers from moderate to severe water stress for at least 1 month per year [6]. By 2025, two-thirds of countries will face water scarcity [7]. The per capita water resources in China are only 1/4 of the world's per capita availability [8]. At present, water resources have become a restrictive factor affecting sustainable economic and social development. Hebei, as one of the "capital circle" regions, is an important part of the national regional development [9]. However, the per capita water resources in Hebei Province are only 1/7 of the national average, which is a serious water shortage area. The shortage of water resources and the imbalance of supply-demand restrict the economic and social development seriously, and it is imminent to allocate and utilize water resources rationally [10, 11].

Water supply-demand balance analysis refers to the analysis of the structural relationship between water supply and water demand in a certain region [12, 13]. Many scholars have studied the water supply-demand and its influencing factors. The prediction of impact factors mainly focuses on population, economy, land use area, and water quota. Fullerton and Cardenas [14] applied a linear transfer function (LTF) for short-term forecasting of water demand for residential and nonresidential customers in Phoenix. Sun [15] used the logistic model and the grey prediction model to predict the population and agricultural irrigation area, respectively. The domestic and agricultural water demand was calculated. Socioeconomic, environmental, and landscape pattern indicators were selected to predict urban water demand by employing a weighted model [16]. The dynamic change of water resources is affected by multiple factors. The study of a single factor is slightly insufficient for simulating water resource demand. As a new generation of water resource management software, the WEAP model can simulate the interaction between various factors [17]. The assessment of specific water resource issues can be placed within a comprehensive framework that better simulates changes in the water system. The WEAP model has been widely used in the balance of water supply-demand due to its comprehensiveness, intuition, and ease of operation. The Water Resources Assessment and Planning (WEAP) and Modular Three-dimensional Finite-difference Ground-water Flow (MODFLOW) models were used to evaluate the water balance in seven water basins of Syria [18]. Zerkaoui et al. [19] analyzed the demand for water resources under the changes of individual factors such as population growth, climate change, and agricultural land use changes and explored the possibility of water resource allocation in Mabtouh watershed. Abdi and Ayenew [20] evaluated the application of the WEAP model in the Ketar subwatershed and used the WEAP model to simulate the hydrological process of the subwatershed. Yang et al. [21] used the WEAP model to evaluate the water shortage in the Beijing catchment area at the watershed scale and discussed the application advantages of the WEAP model in water resource management. Liu et al. [22] established a water energy model by coupling the WEAP and Low Emissions Analysis Platform (LEAP) models and discussed the energy-saving and water-saving effects of different policies in Beijing. The balance of water supply and demand is inseparable from the local social and economic development. It is important to the choice of scale for the study of urban water balance. However, according to the current research, most of the research focuses on the basin scale, and the related research on the administrative area scale is seriously insufficient.

The reasonable prediction of future changes in water resources is of great value to water resource utilization. Scenario analysis has become the main method for studying the response of water resources to changing environmental conditions. Under the assumption that a phenomenon or trend will continue into the future, scenario analysis makes predictions about the possible situations or consequences of a predicted object [23, 24]. Milano et al. [25] analyzed the hydrological-climatic characteristics of water crisis in the SPM basin based on historical monitoring data and proposed the implementation of effective water-saving policies. Wang et al. [26] explored the response of river water quantity and water quality to environmental changes by establishing a combined model of water quantity and water quality in the Luanhe River Basin. Freund et al. [27] used the Soil and Water Assessment Tool (SWAT) and Regional Climate (HIRHAM) models to carry out a scenario analysis of the impact of global change on the water volume of the Black Sea Basin. At present, there are many researches on the response mechanism of natural conditions when setting the scenario of water supply and demand balance. Further, the research of one or several scenarios was focused, but the simulation analysis of comprehensive scenario was limited.

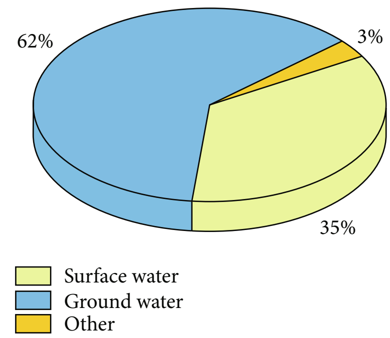

Figure 1: Water supply structure in Hebei Province.

Owing to uneven spatiotemporal distribution of water resources in Hebei, the utilization of water resources varies with cities, and the problem of water supply and demand has become increasingly prominent. Given to the uncertainty of national social and economic development, the establishment of multifactor and all-round scenarios can better provide scientific advice and reference for dealing with future water resource crises. In this paper, the population growth, economic growth, water-saving, and integrated scenarios were established at the administrative district scale. The water resources in Hebei Province were predicted under different scenarios. This study closely combined the balance of water supply-demand with socioeconomic development, which can identify the intraregional differences in water supply-demand, providing theoretical support for water management and sustainable development in Hebei Province. Hebei Province is located in the southeastern part of North China (36° 03′~42° 40′ N, 113° 27′~19° 50′ E), with Beijing and Tianjin in the inner ring and Bohai Sea in the east, which is an important province in North China. Hebei Province has a land area of 188,800 km^2 with high terrain in the northwest and low terrain in the southeast. It is the only province in China with plateaus, mountains, hills, plains, lakes, and seashores. The plain area in Hebei Province accounts for 43.3%, about 81,459 km^2; the mountainous area is 90,280 km^2, accounting for 48.1% of the total area.

The average surface water resources in Hebei Province for many years are 120.17×10^8 m^3, and the distribution of surface water resources is uneven. According to the 2020 Hebei Water Resources Bulletin, Chengde has the most abundant surface water resources, and Hengshui has the least. Moreover, Hebei Province has the most serious overexploitation and the largest funnel area in China, accounting for 1/3 of the total overexploitation area. The groundwater overexploitation plain area in Hebei Province is 67,000 km^2, accounting for 90% of plain area [28].

The average water supply in Hebei Province from 2010 to 2020 was 185.2×10^8 m^3. As shown in Figure 1, groundwater supply accounts for 62% of the total water supply, which is the main water source; surface water and other account for 35% and 3%, respectively. Hebei Province

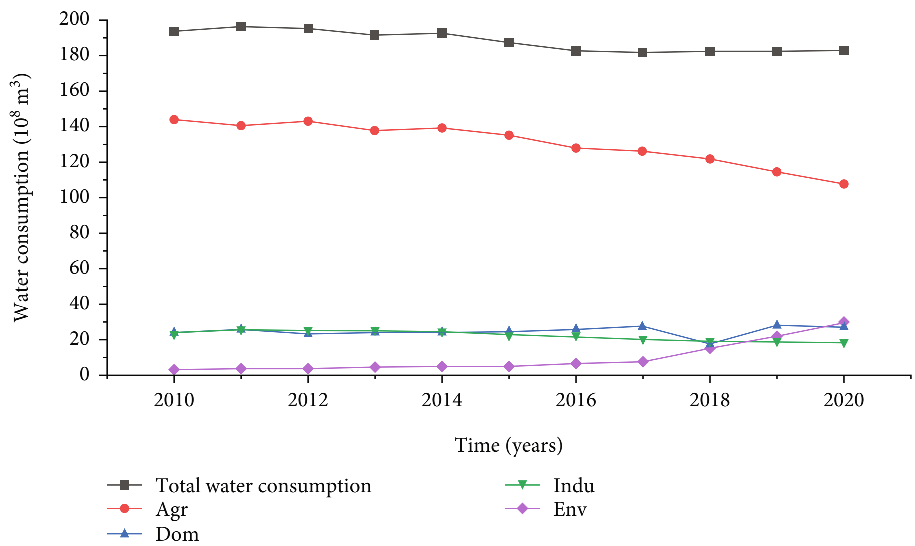

Figure 2: The water consumption structure of Hebei Province from 2010 to 2020.

Table 1: Data sources of the study area.

Data types		Scale	Description	Data sources
Vector data	Geographic		Boundaries, reservoirs, DEM	Geospatial Data Cloud (http://www.gscloud.cn/search)
Water supply	Meteorology	Monthly (1950-2020)	Precipitation, temperature, evaporation	China Meteorological Science Data Sharing Network; European Centre for Medium-Range Weather Forecasts
	Runoff	Monthly (2000-2020)	Streamflow	European Centre for Medium-Range Weather Forecasts
	Reservoir	Yearly (2000-2020)	Initial storage, volume	Hebei Provincial Department of Water Resources, Annual Report on national water situation
	Groundwater	Yearly (2000-2020)	Groundwater initial storage, maximum withdrawal	Hebei Water Resources Bulletin
	Water supply network	Yearly (2000-2020)	Leakage rate of water supply network	Hebei Water Resources Bulletin, China Urban Statistical Yearbook
Water demand	Domestic water	Yearly (2000-2020)	Annual water use rate, consumption, reuse rate	Hebei Statistical Yearbook, Hebei Water Resources Bulletin, Water Resources Bulletin and statistical yearbook of each city, literature
	Industrial water			
	Agricultural water			
	Environmental water			
Social and economic	Population	Yearly (2000-2020)	Resident population, birth rate, mortality rate, natural growth rate	Hebei Statistical Yearbook, Hebei Water Resources Bulletin
	GDP		Industrial added value, water consumption per 1570 dollars of industrial added value	
	Land use		Irrigation area, glassland	Hebei Rural Statistical Yearbook, China Environmental Statistical Yearbook

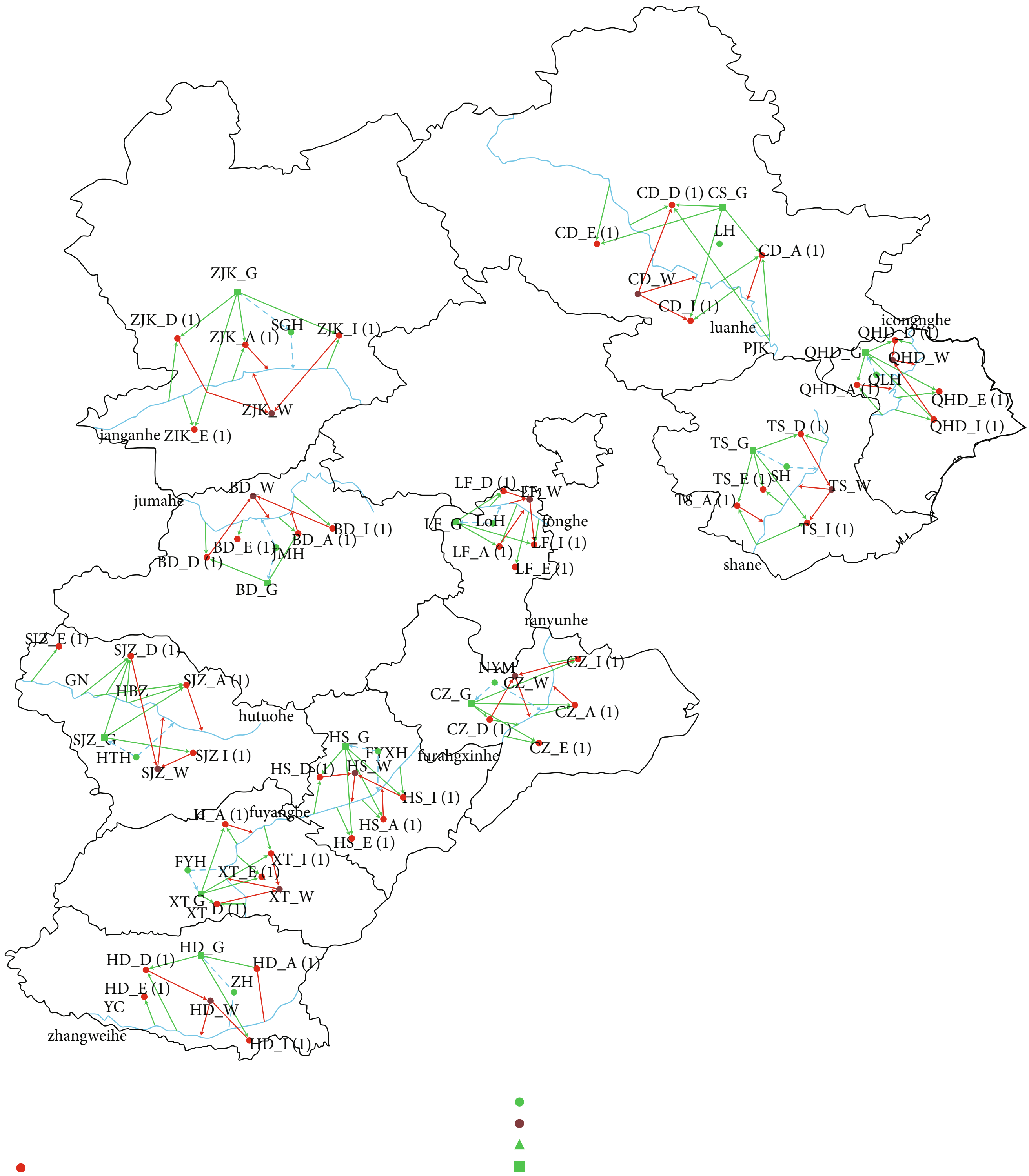

Figure 3: The schematic model of the Hebei WEAP.

Table 2: Key assumptions of the population growth scenarios.

Population change (*P*)	High-speed growth (P1)	Medium-speed growth (P2)	Low-speed growth (P3)
Natural population growth rates (‰)	4	2	0.5

Table 3: Key assumptions of the economic growth scenarios.

Economic development (E)	High-speed growth (E1)	Medium-speed growth (E2)	Low-speed growth (E3)
Growth rate of industrial added value (%)	10	6	4.6

Table 4: Key assumptions of the water-saving scenarios.

Water-saving (W)	High efficiency (W1)	Medium efficiency (W2)	Low efficiency (W3)
Residential water consumption quota (L/(person·d))	60	80	110
Water consumption per 1570 dollars of industrial added value (m^3)	8	10	12
Effective utilization coefficient of farmland irrigation	0.747	0.714	0.68
Reuse rate of industrial water (%)	98	95	93
Leakage rate of water supply network (%)	8	10	12
Glassland water consumption quota ($m^3/m^2·a$)	0.5	0.6	0.7

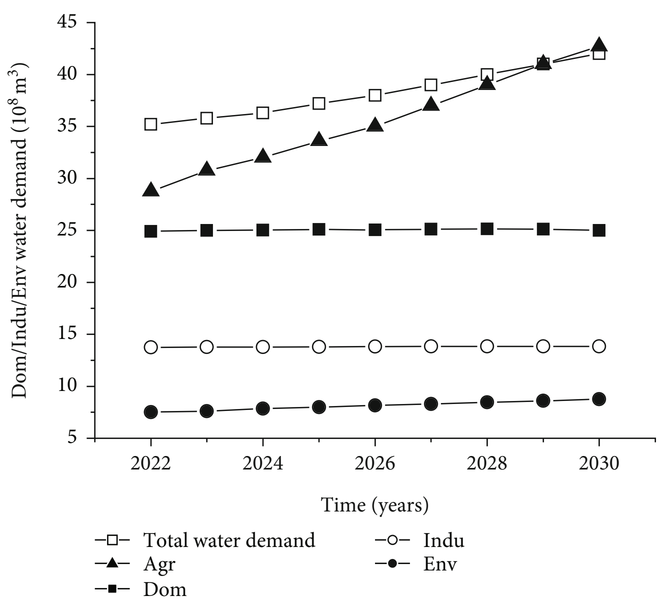

Figure 4: Water demand of different sectors in Hebei Province from 2022 to 2030 under reference scenario.

mainly includes four water use sectors: as shown in Figure 2, total water consumption decreased from 193.68×10^8 m^3 to 182.77×10^8 m^3. The agricultural sector is the main source of water consumption in Hebei Province. Due to the implementation of agricultural water-saving policies, agricultural water consumption has been declining in recent years.

In this work, we proposal a WEAP model to analysis the water resources in China. Reference scenario, population growth scenario, economic growth scenario, water-saving scenario, and 27 integrated scenarios were set up. This study provided a reference for the rational utilization of water resources.

2. Materials and Methods

2.1. Data Collection and Analysis. The spatial vector data used in this study was obtained from the Geospatial Data Cloud (http://www.gscloud.cn/search). The meteorological data was collected from China Meteorological Science Data Sharing Network (http://data.cma.cn/) and European Centre for Medium-Range Weather Forecasts (ECMWF) (https://cds.climate.copernicus.eu/).

In this paper, water supply data mainly includes river runoff, groundwater resources, and reservoir water storage. The water consumption data was divided into four categories: agricultural water, industrial water, domestic water, and environmental water. The socioeconomic data used in this study mainly include the resident population of each city, population birth rate, population mortality rate, natural population growth rate, irrigation area, effective utilization coefficient of farmland irrigation, industrial added value, water consumption per 1570 dollars of industrial added value, leakage rate of water supply network, and reuse rate of industrial water. The data sources include "Hebei Water Resources Bulletin," "Hebei Statistical Yearbook," "Hebei National Economic and Social Development Statistical

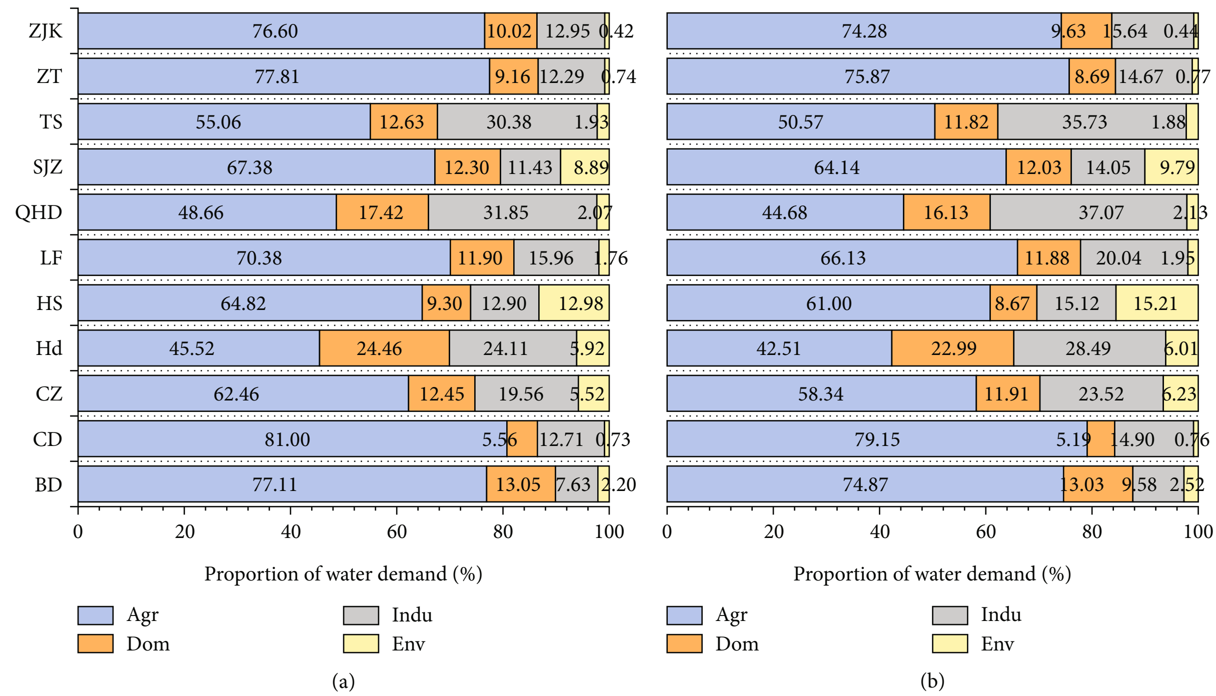

FIGURE 5: Proportion of water demand of cities in Hebei Province under reference scenario: (a) 2025; (b) 2030

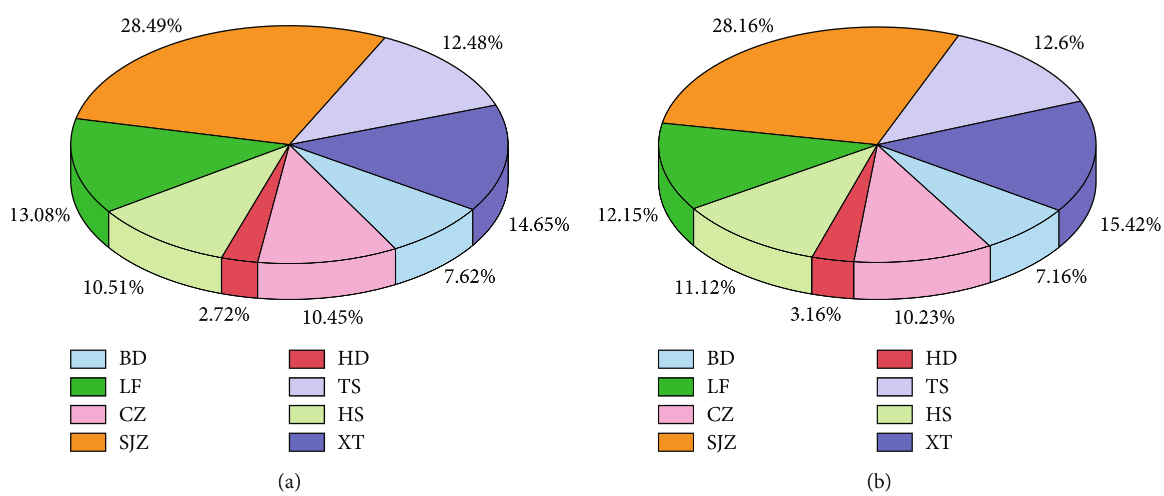

FIGURE 6: Proportion of unmet water demand of cities in Hebei Province under reference scenario: (a) 2025; (b) 2030.

Bulletin," "Hebei Rural Statistical Yearbook," "China Environmental Statistical Yearbook," "China Urban Statistical Yearbook," Water Resources Bulletin and statistical yearbook of each city, and literature. The main data sources are shown in Table 1.

2.2. WEAP Model Description. By generalizing the water resource system, the WEAP model could realize the simulation, prediction, and management of water resources. Generally, the water resource system is generalized into the following elements: demand sites, rivers, catchment basins, reservoirs, groundwater, transmission links, return flows, wastewater treatment, etc. [29]. The WEAP model is a new generation of water resource planning software developed by the Stockholm Environment Institute. It is a comprehensive model that considers water resource development in the context of water supply, water quality, and ecosystems. WEAP software studies a city, a single subcatchment, or a complex river system [17, 30].

2.3. Model Generalization. According to the completeness of data collection, 2011 was used as the current base year in this study, and the water supply-demand from 2022 to 2030 was forecasted. In this paper, month was selected as the time step, and January was taken as the starting year of hydrology. The study area was divided into Baoding (BD),

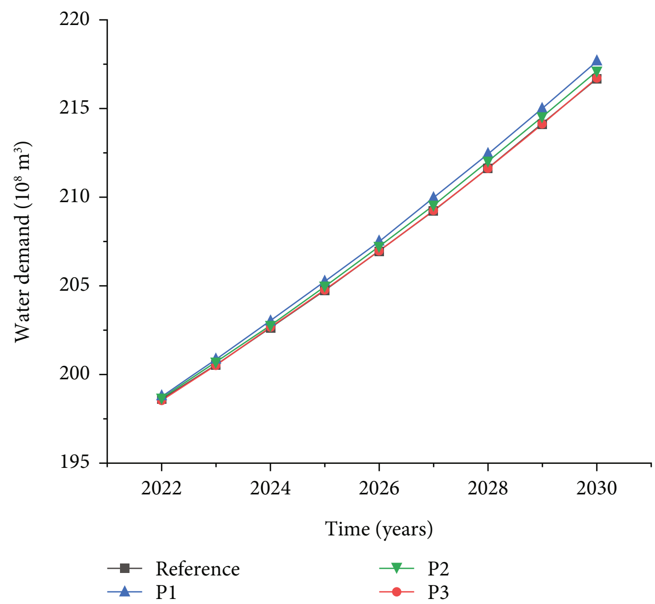

FIGURE 7: Water demand in different population growth scenarios from 2022 to 2030.

TABLE 5: Water demand of different population growth scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High-speed growth (P1)	Medium-speed growth (P2)	Low-speed growth (P3)
2025	204.72	205.22	204.97	204.78
2030	216.64	217.67	217.15	216.77

Chengde (LH), Cangzhou (CZ), Handan (HD), Hengshui (HS), Langfang (LF), Qinhuangdao (QHD), Shijiazhuang (SJZ), Tangshan (TS), Xingtai (XT), and Zhang jiakou (ZJK) (all these cities are located in China). Combined with the characteristics of water consumption in Hebei Province, the water resources system was generalized into a network consisting of rivers, reservoirs, and groundwater as water supply sites and domestic, agricultural, industrial, and ecological water consumption as demand sites. The final generalization of Hebei Province is 44 demand sites, 11 catchment basins, 11 rivers, 11 groundwater nodes, 11 wastewater treatment plant nodes, 22 runoff/infiltration links, 85 transmission links, and 44 return flow links. The generalized diagram of the Hebei WEAP model is shown in Figure 3.

2.4. Model Calibration. To ensure the reliability of the data, the model accuracy needs to be verified. According to the Water Resources Bulletin and the statistics of water consumption data, the water shortage in Hebei Province in 2011 was 68.41×10^8 m^3. The simulation result of unmet water demand in 2011 is 66.65×10^8 m^3, which was close to actual result. Therefore, in this paper, the Hebei WEAP model established could meet the accuracy requirements of the balance analysis of water resource supply-demand.

2.5. Model Scenario Design. Based on the current account year parameters, the reference scenario simulates future changes without the intervention of any external factors, such as new policies and technologies. In the reference scenario, the factors affecting water supply and demand were estimated based on historical years.

Population growth scenarios. Combined with the current socioeconomic development and fertility policies, low-speed growth, medium-speed growth, and high-speed growth scenarios have been set. According to the "Hebei Province Urban System Plan (2016-2030)," the total population will be controlled at about 84 million by 2030. Refer to the "Hebei Province Population Development Plan (2018-2035)" and "National Population Development Plan (2016-2030)," considering the current population changes in Hebei Province; the natural population growth rates of the different scenarios are shown in Table 2.

According to the development goals of the 14th Five-Year Plan of Hebei Province, with reference to the regional GDP of Beijing-Tianjin-Hebei in recent years and the current economic situation, the economic high-speed, medium-speed, and low-speed development scenarios have been established (Table 3).

Based on the "14th Five-Year Plan for Urban and Municipal Infrastructure Construction in Hebei Province," "Hebei Province Water-Saving Action Implementation Plan," "Hebei Province Agricultural Sustainable Development Plan (2016-2030)," "National Water-Saving Action Plan," "Beijing-Tianjin-Hebei Coordinated Development Outline," and "Hebei Water Consumption Quota," water-saving scenarios were set. The main indicators are shown in Table 4.

3. Scenario Analysis

3.1. Reference Scenario Analysis. Based on reference scenario, water demand of different sectors is shown in Figure 4. With the development of social economy and population growth,

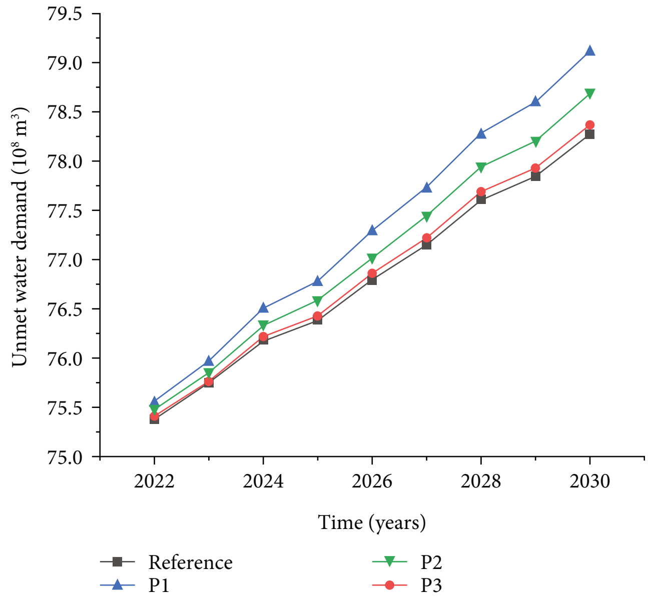

Figure 8: Unmet water demand in different population growth scenarios from 2022 to 2030.

Table 6: Unmet water demand of different population growth scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High-speed growth (P1)	Medium-speed growth (P2)	Low-speed growth (P3)
2025	76.38	76.78	76.58	76.42
2030	78.27	79.12	78.70	78.37

the total water demand has an increasing trend. The total water demand will increase from 194.15×10^8 m^3 in 2011 to 204.71×10^8 m^3 in 2025 and will reach 216.64×10^8 m^3 by 2030. Agricultural, domestic, industrial, and environmental water demand will increase to 138.13×10^8 m^3, 24.93×10^8 m^3, 33.60×10^8 m^3, and 8.05×10^8 m^3 in 2025. By 2030, four categories of water demand will reach 140×10^8 m^3, 25.31×10^8 m^3, 42.89×10^8 m^3, and 9.36×10^8 m^3, respectively. The agricultural sector is the main water-requiring project in Hebei province. In 2025, the agricultural water demand will account for 67.74% of the total water demand, and the industrial, domestic, and environmental water demand will account for 16.41%, 12.18%, and 3.93%, respectively. Compared with 2025, the proportion of industrial water demand will increase, accounting for 19.8% of the total water demand in 2030.

The water demand structure of cities in Hebei Province is shown in Figure 5. In 2025, the agricultural water demand in Chengde and Xingtai will account for a larger proportion of total water demand, 81% and 77.81% in 2025, while Handan and Qinhuangdao account for only 45.52% and 48.66%, but the proportion of domestic water demand is the largest. Qinhuangdao, Tangshan, and Handan will account for the largest proportion of industrial water demand, accounting for 31.85%, 30.38%, and 24.11%, respectively. Hengshui and Shijiazhuang will have a larger proportion of environmental water demand, accounting for 12.98% and 8.89% of the total water demand. By 2030, to a certain extent, the proportion of industrial water demand will increase in all cities. In the future, the industrial development of Hebei Province and the high-tech transformation of traditional industries will become important factors for water demand [31].

The simulation results showed that unmet water demand was derived from agricultural irrigation. In 2025 and 2030, the unmet water demand of agricultural sector will reach 63.39×10^8 m^3 and 63.92×10^8 m^3, accounting for 83% and 81.67% of the total, respectively. According to the future development trend and simulation results, the proportion of environmental and domestic water unmet demand will increase, and the industrial water unmet demand will be less. As shown in Figure 6, the unmet water demand in Shijiazhuang will be the most serious. However, the proportion of water shortage in all cities will decrease by 2030, while the proportion of water shortage in Tangshan, Hengshui, and Xingtai will increase year by year.

3.2. Population Growth Scenario Analysis. Over time and population, the simulation results show a gradual upward trend between population growth scenarios. There is a certain difference in the range of changes between different scenarios. Compared with reference scenario, the P1, P2, and P3 scenarios will increase the water demand by 0.5×10^8 m^3, 0.25×10^8 m^3, and 0.06×10^8 m^3 in 2025. By 2030, water demand will increase by 1.03×10^8 m^3, 0.51×10^8 m^3, and 0.13×10^8 m^3, respectively (Figure 7 and Table 5). Figure 8 and Table 6 show the changes in unmet water demand under population growth scenarios. Under P1, P2, and P3 scenarios, the water shortage in 2025 will increase by 0.4×10^8 m^3, 0.2×10^8 m^3, and 0.04×10^8 m^3, respectively. Compared with reference scenario, while in 2030, it will increase by 0.85×10^8 m^3, 0.43×10^8 m^3, and 0.1×10^8 m^3.

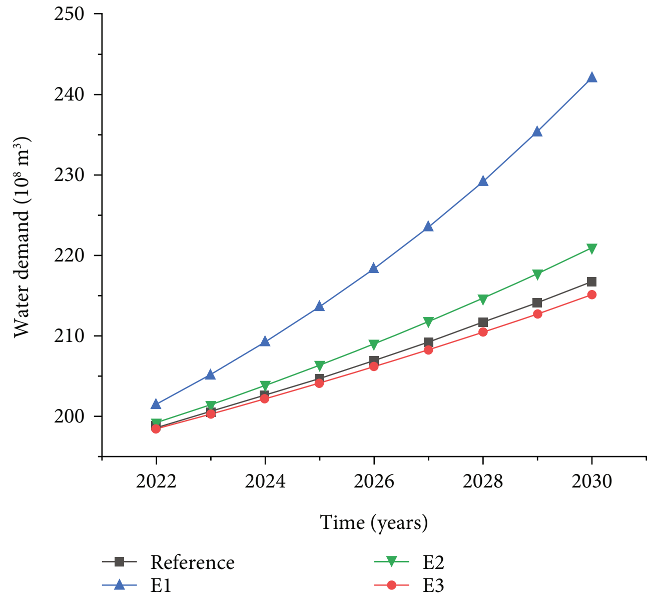

Figure 9: Water demand in different economic growth scenarios from 2022 to 2030.

Table 7: Water demand of different economic growth scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High-speed growth (E1)	Medium-speed growth (E2)	Low-speed growth (E3)
2025	204.72	213.52	206.35	204.08
2030	216.64	242.05	220.91	215.04

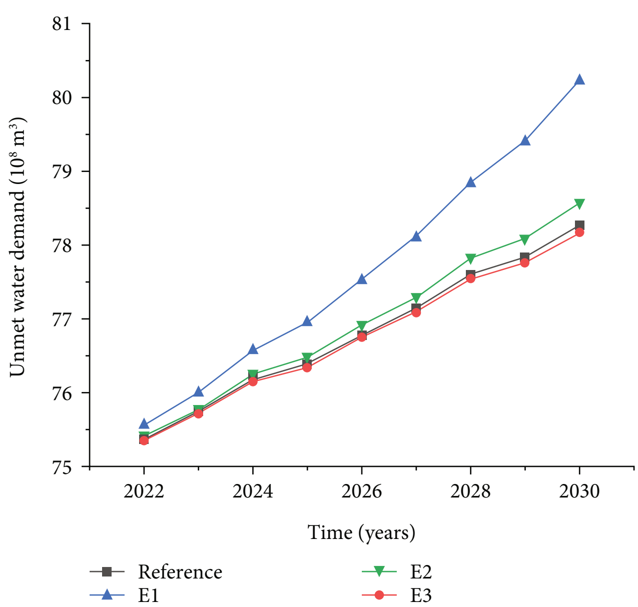

Figure 10: Unmet water demand in different economic growth scenarios from 2022 to 2030.

Due to the large population of Hebei Province, the differences in the simulation results between the population growth scenarios are limited. Additionally, because of the economic and cultural development gap between Hebei and Beijing-Tianjin, the population of Hebei Province has mainly moved out to Beijing and Tianjin for many years [32, 33]. In the absence of large-scale population inflows in Hebei, the local population growth alone has little impact on the carrying capacity of water resources. However, it is necessary to improve the leakage rate and water supply capacity of the water supply pipe network in time.

Table 8: Unmet water demand of different economic growth scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High-speed growth (E1)	Medium-speed growth (E2)	Low-speed growth (E3)
2025	76.38	76.94	76.48	76.34
2030	78.27	80.22	78.56	78.16

3.3. Economic Growth Scenario Analysis. The results show that water requirement and water demand will increase exponentially under economic growth scenarios as a whole. The change rate of industrial added value under the low-speed economic growth scenario is smaller than that of reference scenario, and the unmet water demand is slightly smaller than the simulation results of reference scenario. As shown in Figure 9 and Table 7, compared with E1 and E2 scenarios, the water demand in 2025 will be reduced by 2.27×10^8 m^3 and 9.44×10^8 m^3 under E3 scenario; by 2030, the water demand will be reduced by 4.27×10^8 m^3 and 25.41×10^8 m^3. Under E1 scenario, the water demand in 2025 and 2030 will increase by 8.8×10^8 m^3 and 26.41×10^8 m^3 compared with reference scenario. Under E1, E2, and E3 scenarios, the water demand in 2030 will be 1.25, 1.14, and 1.11 times that of 2011, respectively. As can be seen from Figure 10 and Table 8, compared with reference scenario, the change in unmet water demand is smaller under E2 and E3 scenarios, but larger in the E1 scenario.

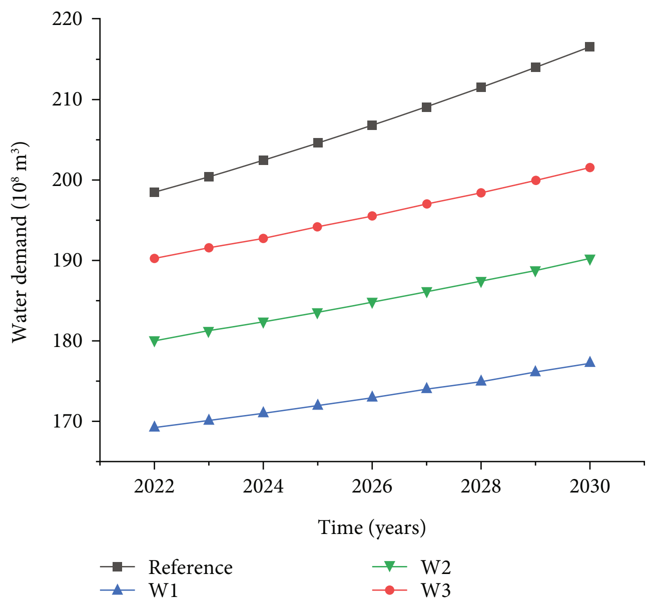

Figure 11: Water demand in different water-saving scenarios from 2022 to 2030.

Table 9: Water demand of different water-saving scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High efficiency (W1)	Medium efficiency (W2)	Low efficiency (W3)
2025	204.72	172.02	183.67	194.21
2030	216.64	177.28	190.28	201.65

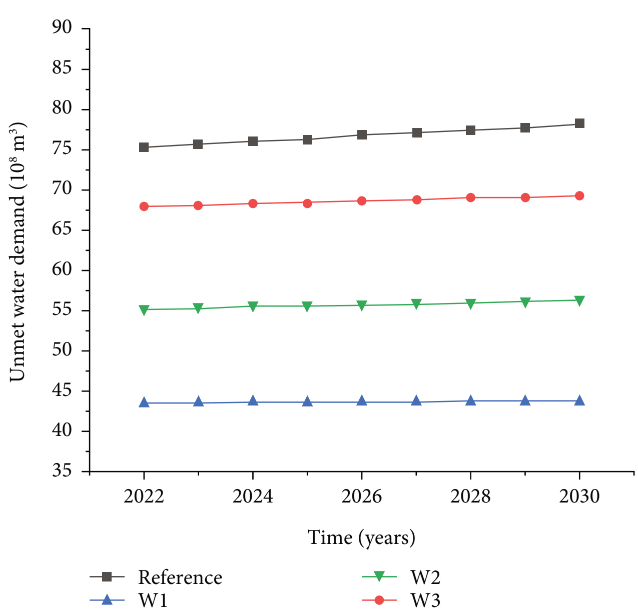

Figure 12: Unmet water demand in different water-saving scenarios from 2022 to 2030.

From the above analysis results, it can be seen that compared with the current year, the economic growth scenarios will increase the pressure on the water supply-demand in Hebei Province in the future. In particular, under the conditions of rapid economic growth, the contradiction between supply and demand of water resources is more prominent. Economic development will have a significant impact on the balance of water supply and demand, which is one of the main factors affecting the water balance.

3.4. Water-Saving Scenario Analysis. For the water demand in Hebei Province, the role of water-saving measures is more obvious. Compared with the reference scenario, under high-efficiency water-saving measures (W1), the water demand in 2025 and 2030 will be reduced by 32.7×10^8 m^3 and 39.36×10^8 m^3, respectively; under the low-efficiency water-saving scenario (W3), the water demand will be reduced by 10.51×10^8 m^3 and 14.99×10^8 m^3 (Figure 11, Table 9). From Figure 12 and Table 10, it can be seen that under the water-saving scenarios, the unmet water demand does not change significantly with time, but the unmet water demand varies greatly under different scenarios. Compared with the reference scenario, the W1, W2, and W3 scenarios will reduce unmet water demand by 8.95×10^8 m^3, 22×10^8 m^3, and 34.5×10^8 m^3 in 2030, respectively.

Liu [34] established a water-saving development scenario for Beijing-Tianjin-Hebei and concluded that water demand and unmet water demand in Hebei will be 186.61×10^8 m^3 and 52.69×10^8 m^3 in 2030. The calculation results are within the simulation results of the three water-saving scenarios established in this paper, which is relatively close to the medium-efficiency water-saving scenario. The water-saving scenarios could reduce the amount of water resources used by changing the water consumption of different sectors, improving the utilization efficiency, and reducing water loss.

Table 10: Unmet water demand of different water-saving scenarios in 2025 and 2030 (unit: 10^8 m^3).

Year	Reference	High efficiency (W1)	Medium efficiency (W2)	Low efficiency (W3)
2025	76.38	43.56	55.59	68.44
2030	78.27	43.77	56.27	69.32

Table 11: The supply and demand of water resources in Hebei Province under S6 scenario.

	Water demand (10^8 m^3)		Unmet water demand (10^8 m^3)	
Year	2025	2030	2025	2030
Reference	204.71	216.64	76.38	78.27
S6	172.94	179.50	43.73	44.12

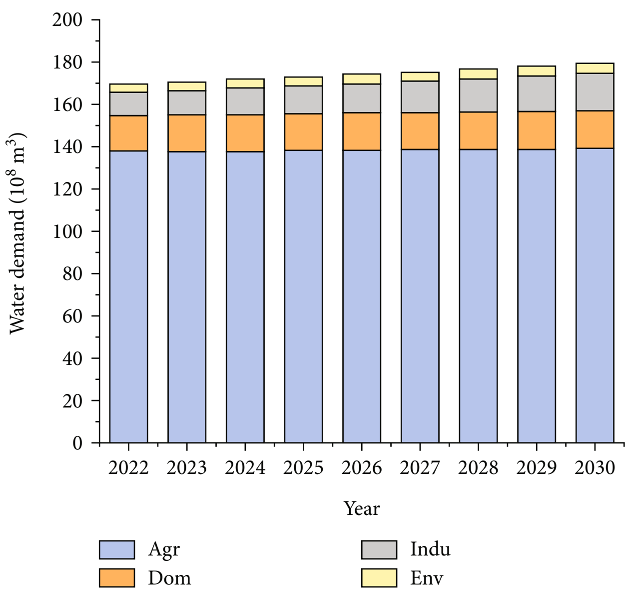

Figure 13: Water demand in different sectors of Hebei Province from 2022 to 2030 under S6 scenario.

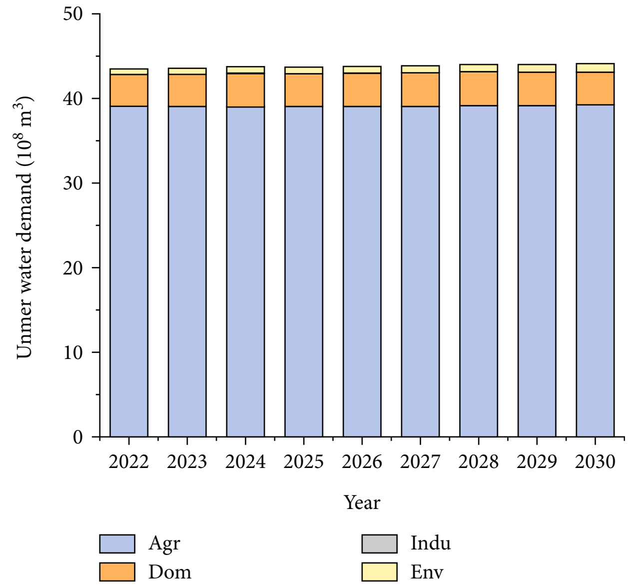

Figure 14: Unmet water demand in different sectors from 2022 to 2030 under S6 scenario.

Table 12: Water demand of each city under S6 scenario (unit: 10^8 m^3).

Scenario	Reference		S6	
Year	2025	2030	2025	2030
BD	29.72	30.23	26.97	27.15
CD	18.97	20.64	17.05	18.27
CZ	14.92	15.84	12.78	13.32
HD	13.08	14.13	10.13	10.81
HS	11.24	12.24	9.05	9.49
LF	14.72	14.96	12.80	12.78
QHD	7.58	8.31	5.30	5.57
SJZ	34.06	35.36	28.17	28.74
TS	28.99	31.46	22.02	23.32
XT	20.31	21.72	18.51	19.50
ZJK	11.12	11.75	10.16	10.56

Compared with the population growth scenario and the economic growth scenario, the water-saving scenario has the greatest impact on water supply-demand. Therefore, under the premise of ensuring normal economic and social development, it is necessary to develop water-saving measures to improve the sustainable utilization and development of water resources.

3.5. Integrated Scenario Analysis. Simulation results of water resources in different scenarios in 2025 and 2030 in Hebei Province are shown in Table S1. Combining with population, economy, and water-saving factors, 27 kinds of scenarios were established to study the impact on water supply-demand under the combined action of three scenarios.

Due to the limitation of space, this paper discussed the balance of water supply-demand by taking "high-speed population growth, medium-speed economic growth, high-efficiency water-saving" (S6) as an example. Under S6 scenario, due to the change of per capita water consumption quota and the improvement of water resource utilization efficiency, the water demand and unmet water demand showed a gradual decreasing trend compared with reference scenario (Table 11).

As shown in Figures 13 and 14, the water demand of industrial sector in Hebei Province will grow faster from 2022 to 2030, but the unmet water demand will be less. The main reason is that water-saving measures have reduced the water consumption of 1570 dollars of industrial added value and improved the reuse rate of industrial water greatly.

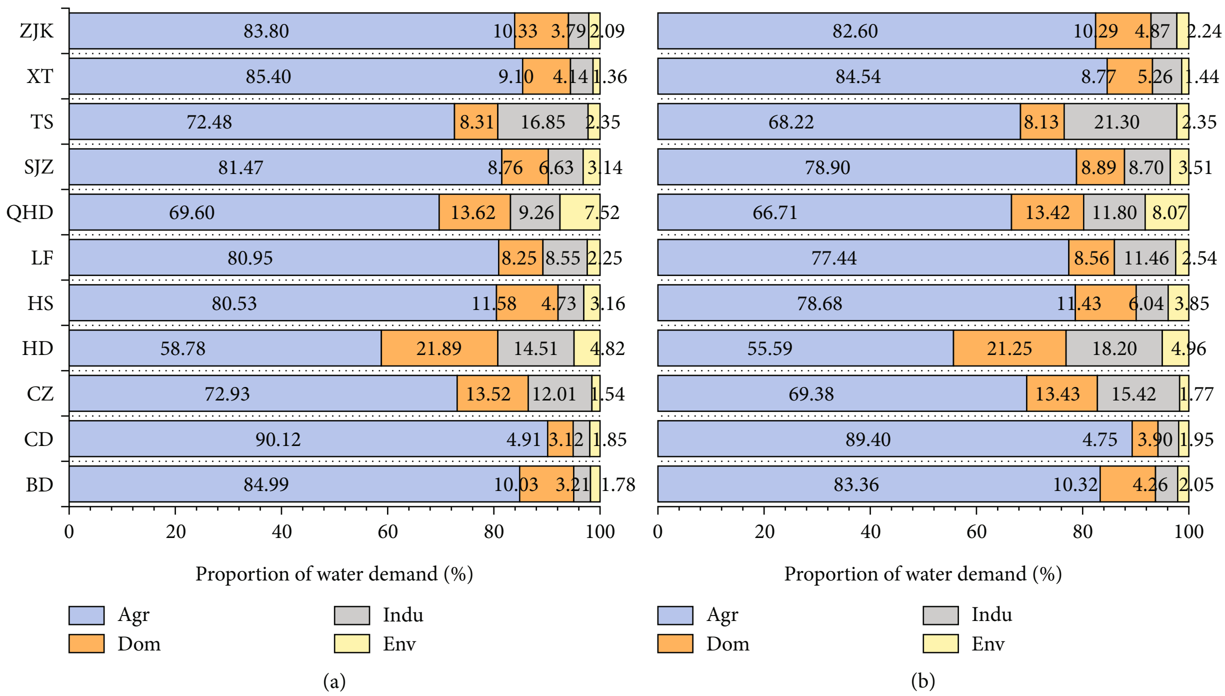

Figure 15: Proportion of water demand of different sectors in cities of Hebei Province under S6 scenario: (a) 2025; (b) 2030.

Table 13: Unmet water demand of each city under S6 scenario (unit: 10^8 m^3).

Scenario	Reference		S6	
Year	2025	2030	2025	2030
BD	5.82	5.61	1.23	1.06
CD	0.00	0.00	0.00	0.00
CZ	7.99	8.01	5.70	5.69
HD	2.08	2.47	0.00	0.00
HS	8.03	8.71	5.34	5.70
LF	9.99	9.51	7.58	7.08
QHD	0.00	0.00	0.00	0.00
SJZ	21.76	22.04	11.89	11.76
TS	9.53	9.86	3.61	3.64
XT	11.19	12.07	8.38	9.19
ZJK	0.00	0.00	0.00	0.00

The results showed that agricultural water consumption will have a downward trend but will account for the vast majority. In the next decade, the water demand and unmet water demand will still be dominated by agricultural water.

Compared with reference scenario, the water demand of each city will decrease (Table 12). Therefore, under the constraints of water-saving measures, despite rapid population growth and moderate economic growth, the contradiction between water supply and demand cannot be exacerbated. Figure 15 showed the proportion of water demand by different sectors in each city in 2025 and 2030. For example, in 2025, the proportion of domestic and industrial water demand in Cangzhou will be 13.53% and 12.01%, respectively, while industrial water demand will exceed the proportion of domestic water demand in 2030. For Tangshan City, the proportion of industrial water demand, domestic water demand, and agricultural water demand will reach 16.85%, 8.31%, and 72.48% in 2025, respectively; in 2030, agricultural water demand will drop to 68.22% and industrial water demand will increase to 21.30%. With the strengthening of ecological protection in recent years, the ecological water demand in various cities is also steadily improving. It can be seen that with the changes of economic society or human activities, the structure of water demand in Hebei Province will also change.

Under S6 scenario, there will be significant changes in unmet water demand. For example, the unmet water demand in Handan City in 2025 and 2030 will be 2.08×10^8 m^3 and 2.47×10^8 m^3, respectively. However, there will be no unmet water demand in Handan under S6 scenario. In addition, the unmet water demand in other cities will also be significantly improved. The contradiction between supply and demand will be greatly alleviated (Table 13 and Figure 16). In 2025 and 2030, the agricultural unmet water demand in all cities will be more than 80%, followed by domestic sector. Due to the improvement of the environment, environmental water demand and unmet water demand are also increasing. It is necessary to further rationally allocate water for the ecological environment.

4. Discussion

4.1. Analysis of Results and Suggestion. Under the coordinated development of Beijing-Tianjin-Hebei, Beijing-Tianjin industries are gradually transferring to Hebei Province. In addition, Hebei Province needs to ensure the safety of water supply and ecological security in Beijing-Tianjin,

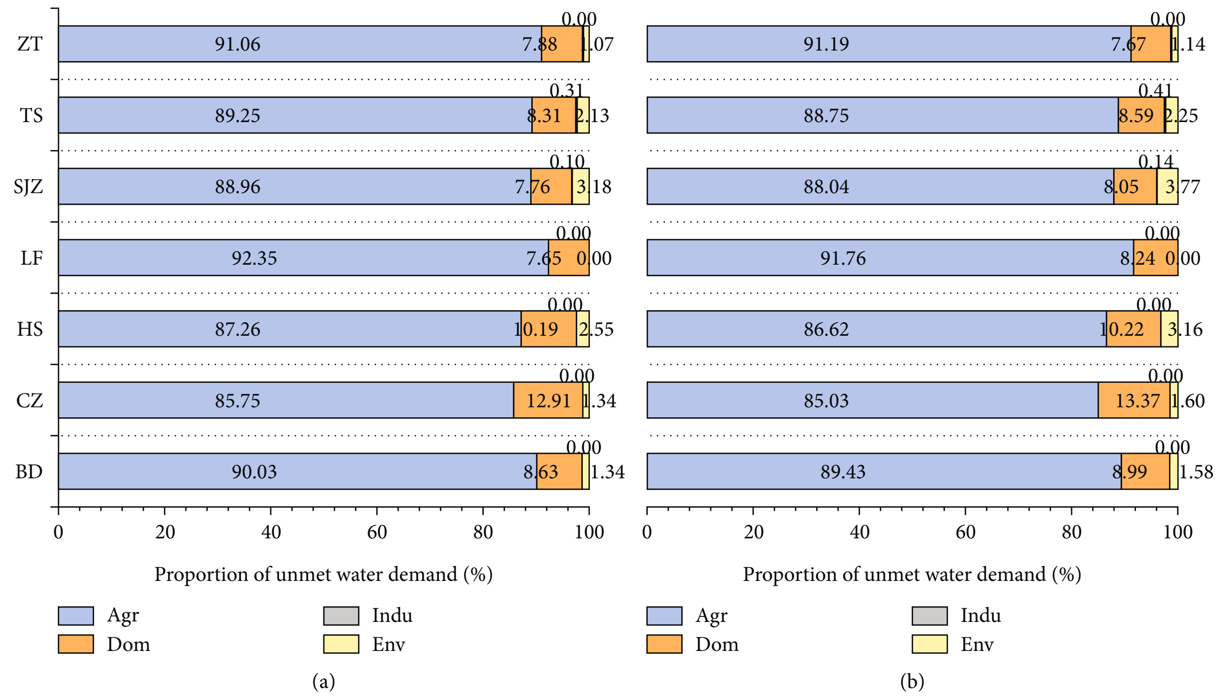

Figure 16: Proportion of unmet water demand of different sectors in cities of Hebei Province under S6 scenario: (a) 2025; (b) 2030.

so that the tension of water supply will further increase. At present, most scholars have evaluated the supply and demand of water resources in Beijing-Tianjin-Hebei [35–38]. However, due to the economic differences in Beijing-Tianjin-Hebei, the development and utilization of water resources are different [38].

From the perspective of each city, there will be no unmet water demand in Handan under S6 scenario. Zhangjiakou, Chengde, and Qinhuangdao still have better utilization of water resources, and there is no water shortage. The research results by Yu et al. [9] and others show that Zhangjiakou and Chengde have better ecological environment and higher water carrying capacity, which are important water conservation areas. However, Shijiazhuang, Cangzhou, Xingtai, Langfang, and Hengshui have a heavy industrial structure and low water resource utilization efficiency, which is consistent with the results of this study [9]. Due to natural conditions and policy factors, the water carrying capacity in central Hebei is higher than that in northern and southern Hebei [39]. The water resources in the central and southern regions of Hebei are generally poor, and the unmet water demand level is relatively high [40]. Zhang et al. [41] analyzed cities in Hebei Province from four dimensions: water ecology, water environment, water quantity, and water use. The study found that the water ecology was suboptimal in Zhangjiakou, Chengde, Tangshan, and Qinhuangdao; Baoding, Cangzhou, Xingtai, and other places had poor water environment; Chengde, Qinhuangdao, and Zhangjiakou had better water quantity; Handan City has a good degree of water use. The water resources are sufficient to support local residents' water use in Handan. Overall, the simulation results in this paper are similar to the previous results. During the "14th Five-Year Plan" period, Hebei Province should take measures to narrow the regional gap [39].

The research in this paper showed that agriculture will be the main water consumption sector in Hebei Province, and industrial water will be relatively less, which indicates that the overall level of economic and industrial development is relatively limited. In terms of water consumption structure, it can be found that the proportion of agricultural and domestic water consumption will gradually decrease, while industrial and environmental water consumption will increase by 2030. Due to the transfer of industries in Beijing-Tianjin, industrial water demand in Hebei Province will increase. At the same time, it can be found that there is almost no industrial unmet water demand in each city, indicating that the improvement of industrial water consumption efficiency can solve the problem of unmet water demand. Because of the enhancement of environmental awareness, the urban greenland has expanded, resulting in an increase in ecological water consumption. For Beijing-Tianjin-Hebei region, Liu et al. showed that the proportion of agricultural and industrial water consumption will continue to decline by 2030, while the proportion of domestic and environmental water consumption will increase to varying degrees, which is different from the analysis results in this study [42].

From population growth, economic growth, and water-saving scenarios, it can be seen that implementation of water-saving measures is the most effective way to in alleviate water shortage. The inefficient use of water resources in Hebei Province shows the low level of industrialization especially in the agricultural sector. By analyzing panel data, Lin et al. [43] believed that economic development was related to regional water use structure and water use efficiency. Population and economic development are closely related to water-saving technologies. Li et al. [44] showed that population carrying capacity and economic development are the main factors affecting the utilization of water resources in Hebei Province. It is necessary to improve water-saving technologies, develop industries with low water consumption, and apply other water supplies on a large scale.

Agriculture and industry are key sectors in policy-making for water resource management in Hebei Province [45]. The research in this paper showed that improving water-saving technology can effectively alleviate the contradiction between water supply-demand. However, the simulation results showed that only using groundwater and surface water resources cannot meet water supply-demand. Due to the uneven distribution of water resources, it is necessary to build interbasin water transfer facilities [46]. The water supply from the South-to-North Water Diversion has a significant effect on alleviating the severe water shortage in Hebei Province [47]. Moreover, it is necessary to rationally plan the water resource utilization model and adjust the industrial structure. The overexploitation of groundwater in Hebei Province is a serious problem. The water-saving irrigation was considered an important way to reduce groundwater depletion [48]. In the agricultural sector, a complete farmland irrigation system should be established, and agricultural planting methods should be adjusted to reduce the proportion of agricultural water use and overall scale. The economic growth is closely related to industrial and agricultural water consumption [28]. To reduce water consumption and the connection between industry and agriculture, it is necessary to develop high value-added industries and high-end service industries and transfer high water-consuming industries. In addition, the government should strengthen the treatment of wastewater, improve the utilization rate of reclaimed water, and encourage the development of environment-friendly fields.

4.2. Shortage of Research. Due to lack of data, agricultural water consumption was entered based on an annual scale in this study. In fact, due to the influence of cultivation time, the agricultural water consumption data in different months are different. A total of 27 kinds of comprehensive scenarios are set up in this paper, but affected by space constraints, only one kind of scenario results was selected for analysis in detail. In this study, only the impact of policy constraints on water resources was considered, and the impact of natural factors was not considered. The impact of natural factors such as climate change on water resources in Hebei Province will be further studied in another manuscript.

5. Conclusions

The WEAP model was established in this paper. Reference scenario, population growth scenario, economic growth scenario, water-saving scenario, and 27 integrated scenarios were set up. The results showed that the local population growth has little impact on the changes in water supply and demand in the absence of large-scale population inflows. Economic development will have a significant impact on the balance of water supply-demand. Under the low-efficiency, medium-efficiency, and high-efficiency water-saving scenarios, compared with reference scenario, the unmet water demand in different water-saving scenarios in 2030 was reduced by $8.95 \times 10^8\,m^3$, $22 \times 10^8\,m^3$, and $34.5 \times 10^8\,m^3$, respectively.

The simulation results showed that the situation of unmet water demand in Hebei Province will be greatly improved by 2030. However, there will still be unmet water demand of $44.12 \times 10^8\,m^3$, mainly due to the unmet water demand of agricultural sector. Further, it is essential to strengthen wastewater treatment and improve the utilization rate of reclaimed water for the supply and demand of water resources.

Data Availability

All data in the current wok can be obtained from the manuscript and through contact with the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Table S1: simulation results of water resources in different scenarios in 2025 and 2030 in Hebei Province *(Supplementary Materials)*

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