Optimizing Water Use Structures in Resource-Based Water-Deficient Regions Using Water Resources Input–Output Analysis: A Case Study in Hebei Province, China

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Abstract: Hebei is a representative province facing the scarcity of water resource in China. China is promoting the coordinated development of Beijing, Tianjin, and Hebei, as well as the establishment of Xiong’an New Area. Hebei Province therefore has to bear the population pressure brought by the construction of Xiong’an New Area, while also absorbing the transfer of industries from Beijing and Tianjin. Therefore, its water supply tensions will be further exacerbated. This study constructed an input–output (IO) table utilizing the input and output data of Hebei in 2015 and analyzed the industrial structure and the characteristics of water usage in relevant industries. The research results show that the agricultural sector in Hebei Province consumes the highest water consumption per 10,000 yuan in output value, while the service and transportation industries are the lowest. And a large amount of water used in the agricultural sector is transferred to the manufacturing sector and construction sector in the form of virtual water. The main way to solve the contradiction between water supply and demand in the typical water-deficient areas represented by Hebei Province is to improve water resource utilization efficiency in the short term, and to change the regional water use structure through industrial structure adjustment in the long term.

Keywords: economic development; water resource; industrial structure; input–output analysis

1. Introduction

Water is an important resource restricting economic and social development. Water scarcity has become a bottleneck restricting the development of many countries and regions [1,2]. According to The United Nations world water development report 2018, regions are considered water scarce when total annual withdrawals for human use are between 20 and 40% of the total available renewable surface water resources, and severely water scarce when withdrawals over 40% [3]. Based on the definition, at present, there are approximately 1.9 billion people living in potentially severely water-scarce areas in the world, accounting for 27% of the global population [3]. Moreover, the shortage of water resources in developing economies has caused the dilemma of environmental sustainability and economic development [4–6]. It has led to an increase in the probability of geopolitical risks [7,8].

As climate continues to change unfriendly to human activities, the supply of water resources from natural cycle would be negatively affected, which would exacerbate water scarcity and further threaten the harmony of human society and nature [1,7]. Even in highly developed regions such as Europe, climate change has exacerbated water shortages in countries such as Poland and Malta, and has adversely affected local economic and social development [9–11]. Therefore, the scarcity of water resources has become one of the major developmental bottleneck factor and evoked deep worry in developing economies [5,6].
Water shortage is particularly serious in the arid and semi-arid areas of Northern China [3]. This problem has seriously affected the sustainable development of this region [3,12]. The agglomeration of industry, population and economic development have further exacerbated the shortage of water resources in arid and semi-arid regions of China [12,13]. Among them, Hebei Province is a typical water-deficient area in northern China (Figure 1). In 2014, China’s per capita water resources accounted for a long time at the level of 2060 cubic meters [14]. Compared with Hebei Province’s per capita water resources that year was 144.3 cubic meters [15]. After 2015, the Chinese central government has gradually increased the supply of water resources to Hebei Province through water transfer across river basins. However, in 2018, the per capita water resources in Hebei Province was still only 217.7 cubic meters, about 10% of the average level in China. According to Table 1, The water shortage in Hebei Province is more serious than those water-scarce regions in Europe, such as Poland and Malta. Due to its perennial unreasonable development and utilization of water resources, its water shortage problem has become more serious [16].

![Figure 1. Location of Hebei Province in China.](image)

| Country or Area | Renewable Internal of Freshwater Per Capita (m³) | Freshwater Withdrawals for Internal Resources (%) | Freshwater Withdrawals for Agriculture (%) | Freshwater Withdrawals for Industry (%) | Freshwater Withdrawals for Domestic (%) |
|----------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------|----------------------------------------|----------------------------------------|
| Hebei China    | 144.3                                         | 181.9                                         | 74.8                                      | 12.7                                   | 12.5                                   |
| China          | 2016.2                                        | 21.3                                         | 64.4                                      | 23.3                                   | 13.3                                   |
| Israel         | 96.6                                          | 260.5                                        | 57.8                                      | 5.8                                    | 36.4                                   |
| Korea, Rep     | 1302.8                                        | 45                                           | 54.7                                      | 15.3                                   | 23.7                                   |
| India          | 1117.6                                        | 44.8                                         | 90.4                                      | 2.2                                    | 7.4                                    |
| Iran           | 1638.8                                        | 72.6                                         | 92.2                                      | 1.2                                    | 7.4                                    |
| Jordan         | N/A                                           | 124.5                                        | 53                                        | 3                                      | 44                                     |
| German         | 1321.3                                        | 30.8                                         | 0.6                                       | 84                                     | 15.4                                   |
| Malta          | N/A                                           | 44.4                                         | 64.0                                      | 2.2                                    | 33.8                                   |
| Poland         | 1410.1                                        | 21.4                                         | 9.6                                       | 72.2                                   | 17.7                                   |
| Netherland     | 652.2                                         | 97.5                                         | 1.1                                       | 87.4                                   | 11.4                                   |

Sources: World Bank WDI database. The data of Hebei Province comes from the 2014 Hebei Water Resources Bulletin [15].
Recently, research on water resources in Hebei Province has mainly focused on the following areas:

1. The impacts of water scarcity on economic development in Hebei Province. For example, Li used an input–output optimization model to study the impact of water scarcity on the potential output of the economy in the southern region of Hebei Province [17]. Lin estimated the correlation between economic growth and water use by industry in Hebei Province using panel data, finding that water use in the agricultural sector had the highest correlation with economic growth [13].

2. Research into industrial development based on the perspective of water scarcity constraints. This type of research is mainly divided into two categories, either single-industry perspectives regarding the optimal use of water resources in Hebei, or studies into the problem of the optimal structure of multi-sectoral industries, based on water resources constraints. Among these, single-industry perspective studies have mainly focused on the impact of agricultural production on water resources in Hebei Province [18,19]. In addition, Sun studied the impact of power structure optimization on reducing water use in the Beijing–Tianjin–Hebei region [20]. Studies into water resources problems in multiple industrial sectors in Hebei Province have also mainly focused on the allocation of industrial structures based on the coupling constraints between water and energy [21,22]. Such studies have tended to analyze optimization problems under water resources constraints. They have downplayed the impact of economic structure, especially regarding the internal linkages of industrial structure on water consumption.

Further research has addressed water utilization problems in Hebei Province from the perspective of urban and rural water use structures [23], but this study only focused on rural and urban water use structures in Hebei Province by consumer group; it did not conduct detailed analysis of the water use structures of sub-industries, nor did it focus on inter-industry water utilization linkages.

However, analysis of the current situation of water resources in Hebei Province shows that it is more appropriate to study this problem from a sub-industry perspective. The reasons for this are as follows: First, in terms of the basic endowment of water resources, Hebei Province is a key region in China that has a severe water resources situation. Second, unreasonable long-term development and utilization patterns have exacerbated water scarcity in Hebei Province. In terms of its industrial structure, Hebei Province is an important grain and cotton production area in China. The province’s main secondary industries are mostly water-intensive, such as construction and coal mining and washing [19]. These industries do not match its water resources endowment [24].

In addition, due to its geographical location and functional zoning factors, Hebei Province has to guarantee the water supply security and ecological security of Beijing and Tianjin, which places more pressure on the regulation and control of its water resources [25,26]. On 1 April 2017, the Chinese central government decided to establish the Xiong’an New Area in Hebei (Figure 2). Alongside the accelerated integration process of Beijing, Tianjin, and Hebei, and the general trend of industrial transfer and upgrading of Beijing and Tianjin, will bring more severe challenges to Hebei Province’s regulation of water resources and socio-economic development [27].

Thus Hebei Province is facing water scarcity and its water resources development and utilization patterns have further aggravated this problem. Furthermore, the industrial undertakings of Beijing–Tianjin–Hebei cooperative development and the construction of the Xiong’an New Area represent further, stringent challenges to the province’s water resources utilization in the future. Therefore, this study selects Hebei Province as a case study area and uses the theory of water resources input–output analysis to analyze its industrial structure and water use characteristics. This study aims to address the following two questions. First, how do the current patterns of industrial water resources consumption and economic development in Hebei province influence the situation of water scarcity? Second, under the condition of ensuring a steady economic development, how to resolve
the issue of water resources scarcity in Hebei province through the adjustment of the patterns of water resources consumption? This study hopes that the answers to these questions will provide decision support and technical support for the water security of typical water-scarce areas such as Hebei Province.

Figure 2. Location of Hebei Province and Xiong’an New District.

2. Materials and Methods

2.1. Research Area

Hebei Province is located in the North China Plain (36°05′–42°40′ N, 113°27′–119°50′ E) east to the Bohai Sea, and both Beijing and Tianjin are surrounded by Hebei. As of 2015, the province had 8532 million m$^3$ of surface water resources and 12,441 million m$^3$ of groundwater resources. After deducting the double-counted amount of surface and groundwater resources, the province has a total amount of water resources of 16,404 million m$^3$ [28]. This value is also only 0.64% of the total water resources of China in the same year [28,29]. In addition, Hebei Province’s per capita water resource consumption is 182 m$^3$, which is far below the national per capita level of 2039 m$^3$ [29–31]. After 2015, the Chinese central government has increased its cross-basin water transfer to Hebei Province through the Middle Route of the South-to-North Water Transfer Project. From 2015 to 2017, a total of 3.125 billion m$^3$ water was transferred to Hebei Province, and the volume of water transferred in 2018 was 2.24 billion m$^3$ [32] This has improved the per capita water resources in Hebei and alleviated the scarcity of water resources in Hebei Province (Table 2).

Moreover, the province has relatively small proportion of surface water resources [29], and the problem of surface water pollution is relatively severe [33], this has led to Hebei
Province’s groundwater supply accounting for 63.9% of the total water supply (2017). At the same time, the proportion of agricultural and ecological water in Hebei Province is too high (Table 3). It directly aggravated Hebei Province’s dependence on groundwater resources, which in turn caused serious groundwater overexploitation in the region. The issue of groundwater overdraft in Hebei Province has led to ground subsidence area of the plain in Hebei Province reached 66,755 square kilometers, accounting for 91% of the total plain area [34] which has seriously threatened the sustainable development of the region [35].

Table 2. 2014–2018 Per capita water resources in Hebei Province, China.

| Year | Per Capita Water Resources (m³/Person) | Freshwater Withdrawals of Internal Resources (%) | Groundwater Supply of Total Water Supply (%) | Water Transfer Supply of Total Water Supply (%) |
|------|--------------------------------------|-----------------------------------------------|--------------------------------|-----------------------------------------------|
| 2014 | 144.3                                | 181.5                                         | 71.37                                          | NA                                         |
| 2015 | 182.5                                | 138.5                                         | 68.46                                          | NA                                         |
| 2016 | 279.7                                | 87.7                                          | 63.88                                          | NA                                         |
| 2017 | 184.5                                | 131.3                                         | 58.17                                          | NA                                         |
| 2018 | 217.7                                | 111.2                                         | 52.88                                          | 12.87                                       |

Resource: Hebei provincial water resources bulletin (2014–2018).

Table 3. 2014–2018 Water Resources Demand Structure in Hebei Province.

| Year | Total Water Consumption (100 Million m³) | Total Agricultural and Ecological Water (100 Million m³) | Total Industrial Water (100 Million m³) | Total Domestic Water (100 Million m³) | Water Consumption Per Capita (m³/Person) |
|------|-----------------------------------------|--------------------------------------------------------|-----------------------------------------|---------------------------------------|-----------------------------------------|
| 2014 | 187.2                                   | 140.3                                                  | 22.5                                    | 24.4                                  | 252.8                                   |
| 2015 | 182.6                                   | 134.7                                                  | 21.9                                    | 25.9                                  | 245.2                                   |
| 2016 | 181.6                                   | 134.3                                                  | 20.3                                    | 27                                    | 242                                     |
| 2017 | 182.4                                   | 135.6                                                  | 19.1                                    | 27.8                                  | 240.7                                   |
| 2018 | 182.3                                   | 136.4                                                  | 18.8                                    | 27                                    |                                         |

Resource: Hebei provincial water resources bulletin (2014–2018).

2.2. Methods

Input-output analysis, also known as input–output economics, was first created by Leontief in 1936 [36–38]. It has been widely used since the 1990s, following the rapid development of computer technology. This analysis has exerted an important impact on economic policy making, as well as on the allocation and management of resources [38–40]. The three core components of input–output analysis are the construction of input–output tables, the analysis of input–output coefficients, and the construction of input–output models [41,42].

One significant advantage of input–output analysis is that it can be used to comprehensively analyze the inputs and uses of resources with the operation of the economic system at the level of the industrial sectors of the social economy. Furthermore, it can be adapted to all levels (from micro to macro) through sectoral or regional splitting and merging [43,44]. Therefore, input–output analysis is an important tool for the comprehensive analysis of water resources use efficiency, and for the rational regulation of water resources [45]. By establishing an input–output table containing the quantity of water resources and an appropriate mathematical model, the industrial structure and its water consumption pattern can be systematically analyzed [46]. Combined with supply-driven effects and inter-regional development planning, this can provide a basis for decision making to achieve optimal water resources allocation and improve water resources carrying capacity [47].

During the early days of water resources input–output analysis, some studies approached water resources utilization by compiling physical water resources input–output tables [48,49]. However, it is very difficult to investigate and obtain data with physical input–output tables, as they can only be applied to very small areas. With the development
of China’s economy and society, the roles of commodity economy and trade in resources allocation have become more important. Therefore, China’s National Bureau of Statistics has been given the responsibility of compiling value-based input–output tables for each region, and for the country as a whole [50]. Value-based input–output tables include resource sectors such as electricity and coal, for which general value-based input–output tables can be directly used for analysis [51]. However, a comprehensive analysis of water resources usage requires the construction of a separate water resources input–output table [49]. In this study, the required water resources input–output table was constructed by inserting individual water resources consumption items [52,53], as shown in Table 4.

Table 4. The input–output table for water resources consumption.

| Input     | Output | Intermediate Use | Final Use | Total Output |
|-----------|--------|------------------|-----------|--------------|
|           | Sector 1 | Sector j | Sector n |                |
|           | x11     | ...       | x1j      | ...          |
|           | ...     | ...       | ...      | ...          |
| Intermediate Input | x1i     | ...       | xij      | ...          |
|           | ...     | ...       | ...      | ...          |
|           | xni     | ...       | xin      | ...          |
|           | ...     | ...       | ...      | ...          |
| Sector n | Xn1     | ...       | xnj      | ...          |
|           | ...     | ...       | ...      | ...          |
| Water Resources Consumption | W1 | Wj | Wn | NA | NA |
| Initial Input | V1 | ... | Vj | ... | Vn | NA | NA |
| Total Input | X1 | ... | Xj | ... | Xn | NA | NA |

As shown in Table 4, water consumption, W, was inserted between quadrants I and III on the basis of the input–output table of Hebei Province from 2015 [54]. Preparation of the water resources input–output table also required further calculations of water consumption by sector, on the basis of the original value-based input–output table [55]. As China’s water resources statistics are only subdivided into three industrial sectors, it was necessary to combine the water resources bulletins and water use quotas of each region to estimate the water use of each subsector. It was also necessary to adjust the water resources input–output table to account for the total water use control and the double proportional scale (RAS); the RAS method is widely used to correct data and will not be elaborated on further in this study [56,57].

For the purpose of establishing an explicit connection between the data of water resources consumption in actual economic activities and the data of water resources input in the input–output table, this study introduced the multipliers for direct water use, total water use, direct output, and total output according to the research conducted by Xie et al. (2013) [58]. The definitions and mathematical expressions of these four multipliers are as follow:

1. **The multiplier for direct water use**

The multiplier for direct water use is the actual use of water resources in a specific sector. On one hand, it represents the water quota allocated to this sector in water resources planning. On the other hand, the multiplier reflects the efficiency of utilizing water resources in the sector. The expression of the multiplier is:

\[ q_j = \frac{W_j}{X_j} \]  

\( W_j \) represents the amount of water resources used in sector \( j \), \( X_j \) represents the total value of output produced by sector \( j \).
(2) The multiplier for total water use

The multiplier for total water use addresses the connection of water resources use among sectors. The production process in one sector always involves intermediate inputs that are goods or service produced by other sectors. To produce such intermediate goods or service also requires the input of water resources in their own producing sectors. However, such consumption of water resources is also necessary to the sectors which utilize those intermediate goods or service. Therefore, the consumption of water resources occurred indirectly in the sectors that utilized the intermediate goods or service is defined as the sector’s virtual water resources [59]. The sum of a sector’s direct consumption of water resources and virtual water resources use is defined as the multiplier for total water use, which reflects the sector’s overall consumption of water resources to generate a unit of output in the industrial system. Let vector Q be the row vector \((q_1, q_2, \ldots, q_n)\), then the multiplier for total water use \(CQ\) can be expressed as:

\[
CQ = Q(I - A)^{-1}.
\]  

(2)

\(CQ\) can also be written in vector form as \(CQ = (Cq_1, Cq_2, \ldots, Cqn)\).

(3) The multiplier for direct output

The multiplier for direct output in a sector represents the value of the output per unit of water resources consumed in the sector, which also indicates the economic benefits of water resources used in the sector. The expression of the multiplier for direct output in sector \(j\) \((O_j)\) is:

\[
o_j = \frac{X_j}{W_j}.
\]  

(3)

(4) The multiplier for total output

Similar to the definition of the multiplier for total water use, the multiplier for total output in a sector represents the overall economic benefits of direct and indirect water resources consumed in the sector. To express the multiplier for total output in a sector, a matrix \(O\) is constructed.

\[
O = \begin{bmatrix}
o_1 \\
o_2 \\
\vdots \\
o_n
\end{bmatrix}.
\]

Using matrix \(O\), the multiplier for total output can be then expressed as:

\[
CO = (I - A)^{-1}O
\]  

(4)

3. Results

Based on the 2015 China inter-regional water resources input–output table, the intermediate input and trade data from regions outside of Hebei Province were consolidated. These data were obtained from the Hebei Province water resources regulation input–output table in the same form as shown in Table 4. Most of the data in the model, such as value added of each industry, residential consumption, and water consumption, can be taken directly from this table. Combined with Figure 3, it can be seen that among the various sectors in Hebei Province, the construction sector has the highest economic share (33.4%), followed by the manufacturing sector (30.03%). The agricultural sector, which ranks third, has a higher share than the finance and real estate sector, the mineral and energy sector, and other sectors. The water supply sector has the lowest value added, which is related to China’s water pricing mechanism, i.e., price subsidies are provided at the national level for resources closely related to people’s livelihoods, such as water resources [60,61].
In terms of water consumption, the sector that consumes the most water in Hebei Province is the agricultural sector, with a total consumption of 13.53 billion m$^3$ (72.2% of total water consumption), followed by the construction sector (2.42 billion m$^3$), and the manufacturing sector with (1.73 billion m$^3$). These three sectors account for more than 94% of the total water consumption in Hebei Province. The data on water consumption in each sector and its share are shown in Figure 4.

The parameters of the model, such as water consumption and input–output coefficients and the consumption-to-income ratio of residents, can be indirectly calculated from the data in the input–output table of water resources regulation. Their calculation methods have been explained in the research described above. The water consumption intensity of each sector in Hebei Province is shown in Figure 5. The agriculture sector has the highest water consumption of 1493.1 tons for 10,000 USD output value, followed by the water supply sector and the construction sector. The service and transportation sector has the lowest water consumption intensity (10.6 tons for 10,000 USD output value). The consumption to income ratio for rural residents is 0.51; for urban residents it is 0.36.
The water resources input–output relationship among the various sectors in Hebei Province is shown in Figure 6. The agricultural sector in Hebei Province is the main water-using sector. Furthermore, it exports a large amount of its water to other sectors in the form of agricultural product inputs, with the manufacturing sector being the most dependent on the agricultural sector, followed by the construction sector, and then the mineral and energy sector. The sector with the second largest amount of water transfer to other sectors is the construction sector. Its water is mainly transferred to the manufacturing sector and the finance and real estate sector. This indicates a high degree of interdependence between these sectors. The manufacturing sector features the third highest transfer; its main transfer targets are the mineral and energy sector, the construction sector, and the agriculture sector, in descending order. The rest of the sectors have weaker relative water transfer relationships and consume less water than the above sectors. In terms of the virtual water transfer of Hebei Province to and from other regions in the country, only the manufacturing sector and the service and transport sector are net virtual water importers; the other sectors are all net virtual water exporters.
in water resources consumption by different industrial sectors and the total consumption. This part of the analysis consists of two main parts. One is the analysis of the changes in the water resources consumption coefficient. This can determine the influence of increasing water use efficiency on the industrial water use in Hebei Province. The other part simulates the impact of changes in industrial structure on the total water consumption in Hebei Province. This will support the subsequent discussion of water use policy adjustments in Hebei Province.

The water consumption coefficient of each sector reflects its water use efficiency and its water saving capacity. To analyze the impacts of changing the water consumption coefficients of the different sectors on the total water resources consumption of the system, a change of $-10\%$ is applied to the water consumption coefficient of each sector, keeping the scale of industrial structure unchanged. The corresponding changes in water resources consumption system are calculated, with the results being shown in Table 5.

### Table 5. Sensitivity analysis table of water consumption coefficient regulation (unit: 100 million cubic meters).

| Water Consumption Coefficient Reduced 10% | Agricultural Forestry and Fishing | Mining and Energy | Finance and Real Estate | Water Supply Department | Manufacturing | Construction | Service and Transportation |
|-----------------------------------------|---------------------------------|-------------------|-------------------------|------------------------|--------------|--------------|---------------------------|
| Change in total water consumption (100 million cubic meters) | $-13.53$ | $-0.52$ | $-0.35$ | $-0.09$ | $-1.73$ | $-2.42$ | $-0.09$ |
| Change rate of total water consumption | $-7.23\%$ | $-0.28\%$ | $-0.19\%$ | $-0.05\%$ | $-0.93\%$ | $-1.29\%$ | $-0.05\%$ |

The data in Table 5 shows that the water consumption coefficient of the agricultural sector has the greatest impact on the overall water consumption of the system, as it is the parameter with the highest sensitivity. For every 10% increase in water use efficiency in the agricultural sector, there is a corresponding reduction of 7.23% in the total system water use; the construction sector and the manufacturing sector show corresponding reductions of 1.29% and 0.93%, respectively. The remaining sectors show relatively weak influences. The above results suggest that Hebei Province should focus on controlling water use in agriculture and construction, upgrade water conservation technologies, and improve water use efficiency.

The simulation of changes in the water consumption coefficient shows that the impacts of different industrial structures on water resources consumption are significant. To specifically analyze the impact of restructuring each industrial sector on the total water consumption, while also considering the recent trend of economic growth in Hebei Province, this study further simulates the changes in the total water resources consumption of Hebei Province when a 10% change is imposed on the value added of each sector (the water consumption coefficient is kept constant). The calculation results are shown in Table 6.

### Table 6. Sensitivity analysis of industrial structure changes.

| Change in Value Added (100 Million USD) | Increase in Water Consumption (100 Million Tons) | Percentage Increase in Water Consumption |
|---------------------------------------|-----------------------------------------------|-----------------------------------------|
| Agricultural forestry and fishing      | 52,798                                        | 10,261                                  | 5.48%                                   |
| Mining and energy                      | 28,445                                        | 1,084                                   | 0.58%                                   |
| Finance and real estate                | 44,106                                        | 0,833                                   | 0.45%                                   |
| Water supply department                | 0,489                                         | 0,054                                   | 0.03%                                   |
| Manufacturing                          | 125,469                                       | 12,543                                  | 6.70%                                   |
| Construction                           | 139,589                                       | 6,147                                   | 3.28%                                   |
| Service and Transportation             | 26,977                                        | 0,185                                   | 0.10%                                   |

The change in value added of each sector in the above table is obtained by increasing the original value added by 10%. Table 3 shows that the growth of the manufacturing,
agriculture, and construction sectors in Hebei Province have the highest dependence on water resources. Due to the high proportion of these sectors in the social economy in the initial state, their absolute increases are large. However, these sectors’ own direct and indirect water consumption coefficients are also high. The agricultural sector and the water supply sector have the highest water consumption per 10,000 USD value added (1943.4 and 1102.2 tons per 10,000 USD, respectively), followed by manufacturing (996.6 tons per 10,000 USD). The other sectors have relatively low water consumption amounts. These values indicate the overall increase in water resources required by the system to increase the value added in each sector by 10,000 USD. This shows that the sensitivity of industrial restructuring varies greatly among different sectors, with agriculture, water supply, and manufacturing sectors being the most sensitive, followed by the construction, mineral and energy, and finance and real estate sectors. The service and transportation sector has the lowest value. Therefore, industrial restructuring should focus on shifting from highly sensitive sectors to less-sensitive sectors.

4. Discussion

4.1. Analysis of the Results

Combining the results of relevant model calculations reveal that the existing industrial structures and development patterns of industries in Hebei Province have aggravated its water scarcity problem. First of all, regarding the overall structure of the province’s industrial water use, the value added of the agriculture sector accounts for 12.64% of the economy. This is much higher than the national average (8.7% for the same year [62]). The economic value added of the manufacturing sector accounts for 30.03%, which is lower than the national average (34.1%) [62].

The higher output share of the agricultural sector and the lower output share of the manufacturing sector mean that the overall level of economic and industrial development in Hebei Province is relatively backward. Luo’s research also shows that the level of industrialization in Hebei Province is lower than the current average level of China [63]. This directly results in the province’s low efficiency of water resources utilization, which is especially obvious in the agricultural sector [64]. In other words, Hebei Province’s agricultural sector produces 12.64% of the economic value added, but consumes 72.2% of the province’s water resources. Its output efficiency is lower than the national average (In that year (2015), China’s agricultural sector accounted for 62.4% of the country’s total water resources use and 8.7% of the value added) [60].

Secondly, analysis of the transmission path of virtual water resources shows that the manufacturing and the construction sectors are strongly coupled with the agricultural sector. These three sectors contribute to more than 70% of the yearly value added for Hebei Province, which shows that economic and industrial development has a strong indirect dependence on the agricultural sector.

Further analysis of the current situation of water resources supply and demand in Hebei Province shows that the total water resources comprise 16.404 billion m$^3$ and the water resources usage is 18.72 billion m$^3$ [29]. Thus, there is a supply–demand difference of 2.218 billion m$^3$. In a region where water resources are extremely scarce, Hebei Province’s economic and industrial development pattern has a strong direct or indirect dependence on the agricultural sector, which is the most water-intensive sector. This indicates that the Province’s industrial development pattern is clearly not reasonable [65].

Meanwhile, sensitivity analysis of the industrial water consumption coefficient shows that even if there were to be no growth in the various industrial sectors in Hebei Province, reducing the water consumption coefficient by 10% would only reduce the water resources consumption by 1.864 billion m$^3$. This would not be sufficient to cover the supply–demand difference. Sensitivity analysis of Hebei Province’s industrial structure shows that the if current development pattern is maintained, a 10% increase in the value added of each sector will increase its water resources consumption by 1.855 billion m$^3$, resulting in a supply–demand difference of 4.073 billion m$^3$. Under this condition, even if the water
resources consumption coefficient of each sector were to continue to increase by 10%, the supply–demand difference in Hebei Province would be 2.114 billion m$^3$, which is basically the same as the current level (2.218 billion m$^3$). It can be seen that relying solely on the improvement of industrial water use efficiency will not solve the water shortage problem in Hebei Province, but it can significantly improve the economic carrying capacity under the existing supply and demand conditions [66].

When further considering the problem of water scarcity in Hebei Province from the perspective of water use by industry, if the ratio of value added of the agricultural sector could be compressed to the national average (8.7%), i.e., a 31.17% reduction in agricultural output would save 4.214 billion m$^3$ of water resources. This would basically solve the water scarcity problem in Hebei Province. This conclusion is basically consistent with the simulation results of Liu et al. using the LMDI Model [21].

However, in terms of the reality of economic and social conditions, in 2017, for example, 13.669 million people were employed in primary industries (Agricultural sector) in Hebei Province. If the ratio of output were to be compressed by 31.17%, this means that other industrial sectors would need to find employment for 4.26 million people. However, the association of other industries with the agricultural sector in Hebei Province shows that it would be difficult for other industrial sectors to absorb such a large scale of employment in a short period of time. Moreover, agriculture, manufacturing, and construction are highly interrelated in Hebei Province. The compression of output in the agricultural sector would therefore inevitably have a great impact on the economic outputs of other sectors in the short term, thus affecting the province’s economic and social development [67].

4.2. Policy Implications

Based on the above discussion, this study believes that in order to solve the issue of water scarcity in Hebei Province requires a systematic rearrangement of its water resources utilization pattern [68,69]. This includes both regulation among industrial sectors and upgrading within industries. The time required for industrial restructuring and the water use demands of Hebei’s economic development should also be considered. Therefore, in the short term it is necessary to increase inter-basin water transfer to alleviate Hebei Province’s strained water resources supply. At the same time, Hebei Province should continue to improve the efficiency of water use in various industrial sectors, especially in the agricultural sector [18,66,68]. In addition, Hebei Province also needs to further improve the utilization efficiency of its wastewater sector and should strengthen the treatment of various types of domestic and industrial wastewater.

In the medium-to-long term, Hebei Province needs to change its industrial development pattern, which includes both industrial restructuring and gradual upgrading within the industry. In terms of industrial restructuring, Hebei Province needs to first reduce the structural share and overall scale of the agricultural sector. Secondly, in terms of upgrading the internal links of its industrial structure, Hebei Province needs to reduce the linkages of the manufacturing and construction sectors with the agricultural sector. This could be achieved by continuously shifting the production links to those with high technology intensity and high economic value add. In addition, to coordinate the smooth implementation of the above policies, Hebei could also create detailed support systems in many areas; for example, trying to raise the price of water resource [70], or by implementing strict environmental supervision.

5. Conclusions

Water is the most basic elemental resource for human life, and environments in which its supply is restricted directly affect the potential for economic development. Given the water resources endowment of Hebei Province and the Beijing–Tianjin–Hebei region, the region has strained water resources, despite the support of a series of major water transfer projects such as the South–North Water Transfer. Groundwater over-exploitation is still severe in Hebei Province, and the resulting ground subsidence and other problems are
directly impacting regional development. Therefore, this study analyzes the water use structure among industries in Hebei Province using the input–output method. High water use is identified in the agricultural sector. Furthermore, the highly coupled management of manufacturing, construction, and other sectors with agriculture within the region limits the improvement of water resources use efficiency in Hebei Province.

The problem of water scarcity in Hebei Province cannot be solved by improving the efficiency of water use in a single industrial sector alone. Hebei Province needs to ensure the sustainable development of its future economy and society by rearranging the industrial structure of its economy and society. To this end, Hebei Province needs to develop an integrated policy of water resources management system based on water resources development constraints. This system should include improving the water use efficiency of existing industrial sectors. At the same time, it should promote the upgrading of the province’s internal industrial structure, including specific measures to reduce the scale of the agricultural sector. It should also focus on the development of industry sectors with lower water consumptions, in addition to reducing the degree of connection between the agricultural sector and the other internal industrial sectors.

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