Decomposition analysis of water utilization in the Beijing-Tianjin-Hebei region between 2003 and 2016

Hongrui Wang, Siyang Hong, Tao Cheng and Xiayue Wang

ABSTRACT

Water crisis is prominent in the Beijing-Tianjin-Hebei region, therefore, the internal relations between water utilization changes and socioeconomic development must be urgently analysed. Based on analyses of the spatiotemporal characteristics of total water utilization, the factors that influenced changes in industrial water utilization in the Beijing-Tianjin-Hebei region from 2003 to 2016 were studied using a factor decomposition model. The results show that the scaling effect (SCE) increased water utilization by 31.78 billion m$^3$ over those 13 years and was the only driving effect that caused industrial water utilization to increase. The structural effect (STE) and technological effect (TEE) reduced industrial water utilization by 14.93 and 20.44 billion m$^3$, respectively. The TEE was the main reason for the decrease in industrial water utilization in Beijing, accounting for a reduction of 96.5% in total industrial water utilization. The STE was stronger than TEE in Tianjin, with associated decreases of 94.65% and 90.1% in total industrial water utilization, respectively. In Hebei, the STE and TEE reduced total industrial water utilization by 60.23% and 85.46%, respectively. Adjusting the industrial structure and promoting water-saving technology are efficient methods of alleviating the water shortage in the study area.

Key words | Beijing-Tianjin-Hebei region, factor decomposition method, spatiotemporal differentiation, water utilization

ABBREVIATIONS

<table>
<thead>
<tr>
<th>SDA</th>
<th>structural decomposition analysis</th>
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<tr>
<td>IDA</td>
<td>index decomposition analysis</td>
</tr>
<tr>
<td>LMDI</td>
<td>logarithmic mean division index</td>
</tr>
<tr>
<td>CDM</td>
<td>complete decomposition model</td>
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</table>

$Y_t$ GDP in period $t$

$Y_0$ GDP in period 0

$A_t$ column vector of the proportion of each industrial sector output in period $t$

$A_0$ column vector of the proportion of each industrial sector output in period 0

$B_t$ column vector of per-unit output of water utilization in each industrial sector in period $t$

$B_0$ column vector of per-unit output of water utilization in each industrial sector in period 0

STE  structural effect

TEE  technological effect

SCE  scaling effect

INTRODUCTION

Water shortages and environmental deterioration in China have become increasingly serious with rapid industrialization and urbanization. The large-scale water supply crisis has severely restricted sustainable socioeconomic development. The Beijing-Tianjin-Hebei region, which is located in the Haihe River basin, is experiencing a serious water shortage. In 2016, the per capita water resources in the region...
totalled only 234.08 m³, which was less than one tenth of the national average level. The total volume of water resources was only 26.2 billion m³, which accounted for just 0.81% of the national total but supported 8.1% of China’s population and 10.16% of GDP. The implementation of the South-to-North water diversion project slightly eased the water scarcity issue in the Beijing-Tianjin-Hebei region, but its effect was quickly offset by the growth in the population. From medium- and long-term perspectives, the implementation cannot overcome the increasing gap between water supply and demand. Since collaborative development in the Beijing-Tianjin-Hebei region has become a topic of national interest, analysing driving factors that influence water utilization provides a scientific basis for formulating efficient water utilization policies. Such analyses are practically significant for the rational allocation of water resources and successful socioeconomic development.

As the gap between water supply and demand widens, scholars are attempting to identify the factors that influence changes in water utilization. Feasible research methods involve conditional inference trees (Fan et al. 2017), non-parametric classification and regression tree methodology (Slavíková et al. 2013), environmental Kuznets curve (Duarte et al. 2012), network analysis simulation (Vairavamoorthy et al. 2008) and some other statistical and econometric models. These methods give reasonable explanations for the influence factors in water utilization from the perspective of statistics, while they generally have high requirements for the calculation model and data. By contrast, factor decomposition techniques, which are widely used in energy fields, provide a new perspective in analysing driving factors in water utilization. This method has a more concise calculation process and lower data requirements, and it is easier to make flexible adjustments of the decomposition targets according to the research purpose. It also has a clear economic meaning and it is easier to realize the transplantation between regions. Common decomposition techniques include structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Hoekstra & van den Bergh 2005). SDA is also called input–output decomposition (IOD). This approach has strong scientific support but is a non-unique decomposition process. Due to its reliance on input–output tables, SDA is non-ideal for time series analyses and regional comparisons. IDA, also known as index number analysis (INA), is relatively simple compared with SDA. IDA can be used for time series analysis and regional comparisons; therefore, it is commonly used in the energy and environmental fields (Ang 2004). Currently, the most common decomposition forms include the logarithmic mean division index (LMDI) (Ang & Choi 1997) and the complete decomposition model (CDM) (Sun 1998). In addition to the energy sector, factor decomposition models have also been widely used in other areas, such as carbon emission (O’Mahony 2013; Marcucci & Fragkos 2015; Mousavi et al. 2017) and industrial pollution discharge (Duro 2010; Fujii et al. 2013).

Factor decomposition techniques have also gained attention in the water resources field. For example, Zhang et al. (2012) decomposed the effects of contributing factors to water footprint change in Beijing by the SDA method, and the results indicated that technological effect (TEE) was the principal contributor to reducing water footprint. Xu et al. (2015) analysed the driving factors for changes in water footprint of crop production by the LMDI method, and they found that structural and technological effects acted as factors for decrease, while surging population and scaling effect (SCE) increased water footprint. Cazcarro et al. (2013) examined how technology, final demand, and input substitution process influence water utilization by SDA model, and results showed technology and intensity factor offset the effect of demand in increasing water utilization. Duarte et al. (2014) analysed the relationship between total water utilization and economic growth globally from 1900 to 2000 and found that economic development and population growth had significant effects on the increasing levels of water utilization, while a decline in the water utilization intensity could reduce total water utilization. Luyanga et al. (2006) conducted decomposition research on the water utilization intensity in Namibia from 1993 to 2001 and showed that if local water utilization efficiency did not improve, industrial structure adjustment would be the only reason for the decrease of total water utilization. These studies verified the rationality of factor decomposition technology in water resources research.

Previous factor decomposition studies of water utilization change have produced various results. However, these studies lack comparative analysis between regions, and few studies have focused on the Beijing-Tianjin-Hebei
region. Coordinated development of the Beijing-Tianjin-Hebei region is an important development strategy which has been vigorously implemented in recent years in China. Coordinated economic development will inevitably be accompanied by the sharing of water resources among regions, and the mutual influence of water utilization between regions has also exceeded any previous period in the Beijing-Tianjin-Hebei region. For some studies in a single part of the Beijing-Tianjin-Hebei region, data have not been updated to be timely, and they fail to reflect the change in water utilization after the implementation of the Beijing-Tianjin-Hebei integration strategy. Comprehensive analysis of the characteristics in water utilization changes and their influencing factors in these three parts has important practical significance. Therefore, in this article, the spatiotemporal characteristics of total water utilization in the Beijing-Tianjin-Hebei region is analysed, and a full decomposition method that has not been applied in water resources before is used to analyse the driving effects of regional industrial water utilization change, and it provides a reference for the utilization and protection of water resources in the region.

**RESEARCH METHODS AND DATA SOURCES**

**Factor decomposition model**

Although LMDI and CDM can overcome residual term issues in decomposition, these improvements use approximations, and their economic significance is often unclear. This article attempts to learn from the complete decomposition method of energy consumption growth proposed by Liang et al. (2009) to analyse the driving effects of industrial water utilization in the Beijing-Tianjin-Hebei region. Specifically, $Y_t$ and $Y_0$ are the GDPs in period $t$ and period 0, respectively. $A_t$ and $A_0$ are column vectors of the proportion of each industrial sector output in period $t$ and period 0, respectively. $B_t$ and $B_0$ are column vectors of per-unit output of water utilization in each industrial sector in period $t$ and period 0, respectively. In this case, each element is the water utilization per unit of added-value output in different sectors. Water utilization in each industrial sector is equal to the added industrial value multiplied by the per-unit output of water utilization. A change in industrial water utilization in period $t$ and period 0 ($\Delta W_{tot}$) can be expressed as $Y_t A_t B_t - Y_0 A_0 B_0$ and can be decomposed as follows:

$$\Delta W_{tot} = Y_t (A_t - A_0) B_0 + Y_t A_0 (B_t - B_0) + (Y_t - Y_0) A_0 B_0$$

(1)

In this formula, the first term on the right side is the water utilization change caused by a change in the share of an industrial sector. This change is called a structural effect (STE) and is calculated based on the per-unit output of water utilization in period $t$. The second term is the water utilization change caused by a change in the per-unit output of water utilization. Such a change is called a TEE and is calculated based on the industrial structure in period 0. The third term is the water utilization change caused by an economic scale change and is called a SCE. The STE and TEE can be transformed to create a second decomposition formula:

$$\Delta W_{tot} = Y_t (A_t - A_0) B_0 + Y_t A_0 (B_t - B_0) + (Y_t - Y_0) A_0 B_0$$

(2)

Unlike formula (1), the STE in formula (2) is calculated based on the per-unit output of water utilization in period 0. The TEE is calculated based on the industrial structure in period $t$. Combining formula (1) and formula (2), the industrial structures and technological levels of the two periods can be considered, and the final decomposition formula can be derived as follows:

$$\Delta W_{tot} = 0.5Y_t (A_t - A_0) (B_0 + B_t) + 0.5Y_0 (A_0 + A_t)$$

$$\times (B_t - B_0) + (Y_t - Y_0) A_0 B_0$$

(3)

where the three terms on the right side of formula (3) are $\Delta W_{str}$, $\Delta W_{tec}$, and $\Delta W_{sca}$. These terms can be expressed as follows:

$$\Delta W_{tot} = \Delta W_{str} + \Delta W_{tec} + \Delta W_{sca}$$

(4)

where $\Delta W_{str}$ is the water utilization change caused by an industrial structure change considering the technological level in period $t$ and period 0, $\Delta W_{tec}$ is the water utilization change caused by a technological level change considering the industrial structure in period $t$ and period 0, and $\Delta W_{sca}$ is the water utilization change simply caused by economic scale expansion. Changes in industrial water utilization can be divided into STE, TEE, and SCE for regional comparison. Compared with other decomposition methods, this method is...
straightforward and provides significant economic meaning. The industrial structure and technological level in period \( t \) and period 0 are integrated and considered, and insufficiently large or small decomposition results are avoided. However, changes in the industrial structure and technological level can have positive or negative effects on water utilization. Additionally, expanding the economic scale will only increase the demand for water resources; thus, the associated influence on industrial water utilization should be positive.

**Data sources and processing**

The proposed factor decomposition model of changes in industrial water utilization requires the GDP, the proportion of added value in various sectors, and the per-unit added value of water utilization in various industrial sectors. This study is based on data from 2003 to 2016, as statistical classification and analysis methods of water utilization data have changed since 2003. Added-value and water utilization data from the three main industries in the Beijing-Tianjin-Hebei region were obtained from the China Statistical Yearbook. The water utilization data from 2011 were obtained from the ‘China Water Conservancy Yearbook 2012’ because the sub-regional water utilization data in the ‘China Statistical Yearbook 2012’ are from 2010. Due to the differences in the economic and water utilization data sets, economic data were divided into three industrial sectors, and total water utilization data were divided into agricultural water utilization, industrial and construction water utilization, domestic water utilization (including public water) and environmental water utilization. The following steps were performed to match the two division schemes. In the water utilization data, residential water utilization was deducted from domestic water utilization. The result was considered tertiary industrial water utilization, which includes the water utilization of the construction industry. In the economic data, the construction industry was merged with tertiary industry to match the approach used for the water utilization data. Residential water utilization data in Tianjin and Hebei Provinces were obtained from the ‘China Water Resources Bulletin’. Residential water utilization data for Beijing were estimated based on the water quotas of residents multiplied by the population according to the approach proposed by Lei et al. (2004). The residential water quota in Beijing is 102.9 L/(person \( \cdot \) d), as stipulated by the ‘Industry Water Quota References’ published by the Ministry of Water Resources. Population data were obtained from the ‘China Statistical Yearbook’. In addition, to compare data in the various industries, the added value in each year was converted to the comparable price in 2003.

**SPATIAL AND TEMPORAL CHARACTERISTICS**

As a region known for its water shortages, the Beijing-Tianjin-Hebei region serves important socioeconomic functions and has an extremely large water demand. To reduce the growing gap between water supply and demand in recent years, the Beijing-Tianjin-Hebei region adopted a series of water-saving measures. Constantly optimizing industrial structure and promoting water-saving technology, the government desires to improve the water utilization efficiency of the region. The total water utilization in the Beijing-Tianjin-Hebei region remained stable from 2003 to 2016 at approximately 25.4 billion m\(^3\), with variations of less than 0.7 billion m\(^3\) (refer to Figure S1 in the Supporting Information, available with the online version of this paper). During the 13-year period, the total water utilization in the Beijing-Tianjin-Hebei region decreased by nearly 0.7 billion m\(^3\), or 2.7%. Notably, the total GDP in comparable prices increased by 4.22 trillion yuan over the same period, or an increase of 300%. Water utilization in the Beijing-Tianjin-Hebei region did not increase with the rapid growth of the economy. Rather, consumption decreased, which demonstrates an ideal state between economic growth and water utilization.

Hebei Province accounted for more than 70% of the total water utilization in the Beijing-Tianjin-Hebei region. The total change in water utilization in Hebei was similar to the total water utilization trend in the Beijing-Tianjin-Hebei region. Specifically, the total water utilization in Hebei decreased from 19.98 billion m\(^3\) in 2003 to 18.26 billion m\(^3\) in 2016, a decrease of 8.62% over 13 years. The total water utilization in Beijing increased from 3.5 billion m\(^3\) in 2003 to 3.88 billion m\(^3\) in 2016, a 10.86% increase over 13 years. The total water utilization of Tianjin was less than that of Hebei and Beijing. A significant increase occurred from 2003 to 2005, and water utilization then fluctuated at approximately 2.3 billion m\(^3\). Overall, the total water utilization in Tianjin...
increased from 2.05 billion m$^3$ in 2003 to 2.72 billion m$^3$ in 2016, a 32.64% increase over 13 years. Although the total water utilization in Beijing and Tianjin increased, the decrease in total water utilization in the Beijing-Tianjin-Hebei region could be attributed to the decrease in Hebei.

Based on water utilization structure (refer to Supporting Information Figure S2, available with the online version of this paper), environmental water usage was less than industrial water and domestic water usage in the Beijing-Tianjin-Hebei region. However, the rate of environmental water usage increased faster than the rates of industrial water and domestic water usage. Notably, the environmental water usage increased from 0.16 billion m$^3$ in 2003 to 2.19 billion m$^3$ in 2016, an increase of more than 12-fold over 13 years. Slowly, domestic water utilization increased as the population increased, changing from 2.38 billion m$^3$ in 2003 to 3.25 billion m$^3$ in 2016, or an increase of 36.55%. Industrial water utilization was much higher than domestic water and environmental water utilization and accounted for more than 80% of water utilization in the study period. Despite slight fluctuations in 2005, 2006 and 2011, industrial water utilization exhibited an overall decreasing trend, with the largest decline in 2008. Industrial water utilization decreased from 22.99 billion m$^3$ in 2003 to 19.41 billion m$^3$ in 2016, a decrease of 15.59%. Overall, industrial water utilization accounted for the largest proportion of total water utilization and its trend highly influenced the total water utilization trend. Thus, we focus on changes in industrial water utilization to better understand the influence of socioeconomic development on water utilization in the Beijing-Tianjin-Hebei region.

**DRIVING EFFECT ANALYSIS**

**Temporal changes**

Based on the factor decomposition model (Table 1), the STE, TEE, and SCE on changes in industrial water utilization from 2003 to 2016 in the Beijing-Tianjin-Hebei region were analysed. The SCE was positive and increased the water utilization in every period. STE and TEE were negative and reduced the water utilization in every period. Specifically, the SCE increased industrial water utilization by 31.78 billion m$^3$, and the STE and TEE reduced industrial water utilization by 14.93 billion m$^3$ and 20.44 billion m$^3$, respectively. The decomposition results showed that the expansion of the economic scale was the only factor that led to the increase in industrial water utilization in the Beijing-Tianjin-Hebei region. Adjustments to industrial structure and improvements in water utilization efficiency offset the increase in water utilization caused by economic expansion and decreased industrial water utilization in the Beijing-Tianjin-Hebei region during the study period. The positive STE on industrial water utilization was mainly caused by the enhancement of water utilization efficiency. However, industrial structure developed in a water-saving direction. The positive TEE on industrial water utilization was mainly a result of the promotion of water-saving technology and the improvement of water utilization efficiency.

Specifically, the SCE steadily decreased during the study period, and a sharp decrease occurred in 2010, which might have been caused by the slowdown in GDP growth. Despite the fluctuation between 2007 and 2008, STE positively affected industrial water utilization before 2010, but the effect gradually diminished after 2010. TEE fluctuated

**Table 1** | Decomposition of industrial water utilization in the Beijing-Tianjin-Hebei region (2003-2016)

<table>
<thead>
<tr>
<th>Period</th>
<th>Scaling effect (billion m$^3$)</th>
<th>Structure effect (billion m$^3$)</th>
<th>Technological effect (billion m$^3$)</th>
<th>Industrial water utilization change (billion m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2004</td>
<td>3.16</td>
<td>-1.17</td>
<td>-2.52</td>
<td>-0.53</td>
</tr>
<tr>
<td>2004-2005</td>
<td>2.96</td>
<td>-1.23</td>
<td>-1.26</td>
<td>0.47</td>
</tr>
<tr>
<td>2005-2006</td>
<td>3.10</td>
<td>-1.50</td>
<td>-1.34</td>
<td>0.27</td>
</tr>
<tr>
<td>2006-2007</td>
<td>3.22</td>
<td>-1.73</td>
<td>-1.77</td>
<td>-0.27</td>
</tr>
<tr>
<td>2007-2008</td>
<td>2.50</td>
<td>-1.06</td>
<td>-2.49</td>
<td>-1.05</td>
</tr>
<tr>
<td>2008-2009</td>
<td>2.49</td>
<td>-1.30</td>
<td>-1.28</td>
<td>-0.09</td>
</tr>
<tr>
<td>2009-2010</td>
<td>2.77</td>
<td>-1.49</td>
<td>-1.58</td>
<td>-0.30</td>
</tr>
<tr>
<td>2010-2011</td>
<td>2.47</td>
<td>-1.14</td>
<td>-1.21</td>
<td>0.11</td>
</tr>
<tr>
<td>2011-2012</td>
<td>2.18</td>
<td>-0.94</td>
<td>-1.48</td>
<td>-0.24</td>
</tr>
<tr>
<td>2012-2013</td>
<td>1.95</td>
<td>-0.86</td>
<td>-1.48</td>
<td>-0.40</td>
</tr>
<tr>
<td>2013-2014</td>
<td>1.64</td>
<td>-0.72</td>
<td>-0.97</td>
<td>-0.05</td>
</tr>
<tr>
<td>2014-2015</td>
<td>1.86</td>
<td>-1.13</td>
<td>-1.47</td>
<td>-0.74</td>
</tr>
<tr>
<td>2015-2016</td>
<td>1.48</td>
<td>-0.66</td>
<td>-1.59</td>
<td>-0.77</td>
</tr>
<tr>
<td>2003-2016</td>
<td>31.78</td>
<td>-14.93</td>
<td>-20.44</td>
<td>-3.59</td>
</tr>
</tbody>
</table>
during the study period and led to decreases in industrial water utilization of 2.52 billion m$^3$ and 2.49 billion m$^3$ from 2003 to 2004 and 2007 to 2008, respectively. Due to improvements in water utilization efficiency, industrial water utilization decreased by 0.53 billion m$^3$ from 2003 to 2004. From 2007 to 2008, industrial water utilization decreased by 1.05 billion m$^3$ because of positive SCE and TEE. Additionally, the STE and TEE were similar before 2010. However, after 2010, the decrease in industrial water utilization associated with the TEE exceeded the increase associated with structure effects. When the water-saving effects of industrial structure adjustment began to weaken, relevant departments could only promote and improve water-saving technology to reach a certain rate of economic growth and relieve pressure on industrial water utilization in the Beijing-Tianjin-Hebei region.

Spatial changes

The proposed factor decomposition model was used to analyse the change in industrial water utilization in each period in Beijing, Tianjin and Hebei (Figure 1). The SCE in Beijing, Tianjin and Hebei and the overall region were positive. After 2010, the SCE exhibited a downward trend, and STE and TEE were both negative. Figure 1(a) shows that industrial water utilization in Beijing decreased in every period, except for 2010–2011 and 2012–2013. Additionally, the TEE in Beijing in each period was higher than the STE because tertiary industry, which had the highest water utilization efficiency, was dominant in the national economy. The industrial structure of Beijing has little room for improvement; therefore, enhancing water-use efficiency was one of the main ways of reducing industrial water utilization. The trends of the influencing factors are consistent with the research findings in the literature of Zhang et al. (2012). The difference is that the main decomposition subject is total water utilization in this article, technological and STE offset the increase in water utilization due to the SCE, and the total water utilization shows a downward trend, while in Zhang et al. (2012) the main decomposition subject is water footprint, which includes internal water footprint and external water footprint. Water is constantly flowed into the study area by economic circulation, therefore, the combined effects of technological progress and structural adjustment still cannot offset the growth in water footprint brought by industrial scale and economic system efficiency. The decomposition results of industrial water utilization change in Tianjin (Figure 1(b)) show that when the SCE increased, the positive impact of the STE on industrial water utilization also increased. These factors offset the growth in industrial water utilization caused by economic expansion. Fluctuations in the TEE led to fluctuations in industrial water utilization in the study period. The overall trend of the influencing factors is consistent with the findings in the study of Shang et al. (2017), however, the specific values are slightly different. The reason may be that in the calculation process, the comparable price in 2003 is adopted as industrial output in this article, while it is not used in the study of Shang et al. (2017). The total industrial water utilization in Hebei was larger than the consumption in Beijing and Tianjin (Figure 1(c)) and highly influenced overall industrial water utilization in the Beijing-Tianjin-Hebei region. Due to the rapid expansion of the heavy chemical industry in Hebei Province in recent years, the proportions of primary industry and tertiary industry (including the construction industry) have decreased. This change led to a decrease in the impact of STE on industrial water utilization after 2010, and the associated reduction in industrial water utilization was smaller than the change caused by the TEE.

From the perspective of the SCE, the proportion of cumulative growth in industrial water utilization caused by economic scale expansion in the initial year of the study period was 116.44%, 196.89%, and 129.97% in Beijing, Tianjin and Hebei, respectively. Tianjin led Hebei and Beijing in SCE on industrial water utilization and economic growth rate. From the perspective of the STE, industrial water utilization in Beijing decreased by 51.57% due to industrial structure adjustment, and the proportions in Tianjin and Hebei were 94.65% and 60.23%, respectively. The inhibitive influence of structure effects on industrial water utilization was largest in Tianjin, followed by Hebei and Beijing. From the perspective of the TEE, improvements in water utilization efficiency decreased industrial water utilization by 96.5%, 90.1%, and 85.46% in Beijing, Tianjin and Hebei, respectively. The inhibitive influence of the TEE on industrial water utilization was largest in Beijing, followed by Tianjin and Hebei. Overall, the TEE was largely
responsible for decreasing industrial water utilization in Beijing. The STE was larger than the TEE in Tianjin. Additionally, compared with Beijing and Tianjin, Hebei has the greatest potential to decrease its industrial water utilization via industrial structure adjustment and improving its water utilization efficiency.
CONCLUSION AND PROSPECTS

Based on analyses of the temporal and spatial characteristics of total water utilization, the factors that influenced changes in industrial water utilization in the Beijing-Tianjin-Hebei region from 2003 to 2016 were studied by a factor decomposition model. The main conclusions of this study are as follows.

(1) Water utilization in the Beijing-Tianjin-Hebei region has remained stable over the past 13 years. Rapid GDP growth did not cause a corresponding increase in water utilization. In the case of increased environmental and domestic water usage, SCE reduced industrial water utilization by 15.59%. During the 13-year period, this reduction was the main factor that permitted the decoupling of economic growth and water utilization.

(2) The SCE was the only driving factor that led an increase in industrial water utilization in the Beijing-Tianjin-Hebei region. Notably, utilization increased by 31.78 billion m³ due to the SCE during the 13-year period. The STE and TEE generally reduced industrial water utilization and resulted in overall decreases of 14.93 billion m³ and 20.44 billion m³, respectively. If industrial structure adjustments and water utilization efficiency improvements had not occurred, the utilization increase could have reached 138.17% over the 13 years in the Beijing-Tianjin-Hebei region.

(3) The inhibitive influence of structure effects on the growth of industrial water utilization in the Beijing-Tianjin-Hebei region substantially increased prior to 2010 and then weakened. Tianjin exhibited the largest STE on industrial water utilization, with a utilization decrease of 94.65% during the 13-year period. In Beijing, where limited industrial structure adjustments occurred, the impact of the STE reduced industrial water utilization by 51.57%. Hebei exhibited the greatest potential for future improvements, as the STE reduced water utilization by 60.23%.

(4) The TEE fluctuated during the study period, and the associated inhibitive influence on industrial water utilization surpassed that of the STE after 2010. The influence of the TEE became the main factor that reduced industrial water utilization in the Beijing-Tianjin-Hebei region. Specifically, the TEE reduced industrial water utilization by 85.46% in Hebei Province during the 13-year period. Overall, water savings overcame the STE but not the TEE on industrial water utilization in Beijing and Tianjin (96.5% and 90.1%). Hebei Province is a key area for reducing water utilization in the Beijing-Tianjin-Hebei region. With coordinated development in the Beijing-Tianjin-Hebei region and the ongoing industrial relocation in Hebei Province, policymakers must avoid increasing industrial water utilization.

Just as in any case study, limitations exist in this study. Several shortcomings and corresponding prospects are listed below. First, this study targets only the Beijing-Tianjin-Hebei region, and future studies are necessary to explore other regions with different economic functions so as to analyse differences of influence factors in water utilization changes. Second, due to differences in the economic and water utilization data sets, the construction industry, which is a secondary industry, was divided into a tertiary industry. Spatial difference analysis did not further subdivide the regions of Hebei Province due to data limitations, therefore, these will affect the accuracy of the research. More concrete conclusions could be obtained if more detailed sectional and regional data were available. Third, unlike non-renewable resources and energy, water resources are not completely consumed in the utilization process. Researching the relationship between water utilization and socioeconomic development from the perspective of water consumption would be more scientific, and this approach will be a direction for future research. Finally, almost all previous studies are associated with historical analysis, by quantifying those underlying forces in change, factor decomposition might be used to project future water utilization, and a 13-year time-span is relatively short to reflect the change rule between regional water utilization and economic development, especially in regions with rapid economic development. Data should be constantly collected and prolonged in future research.

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CONFLICTS OF INTEREST

There are no conflicts of interest.

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