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Analysis on Impact Factors of Water Utilization Structure in Tianjin, China

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Abstract: Water is an essential foundation for socio-economic development and environmental protection. As such, it is very critical for a city's sustainable development. This study analyzed the changes in water utilization structure and its impact factors using water consumption data for agricultural, industrial, domestic and ecological areas in the city of Tianjin, China from 2004 to 2013. On this base, the evolution law and impact factors of water utilization structure were depicted by information entropy and grey correlation respectively. These analyses lead to three main results. First, the total amount of water consumption in Tianjin increased slightly from 2004 to 2013. Second, the information entropy and equilibrium degree peaked in 2010. From 2004 to 2010, the water utilization structure tended to be more disordered and balanced. Third, the economic and social factors seemed to influence the water utilization structure, while the main impact factors were industrial structure, per capita green area, cultivated area, effective irrigation area, rural electricity consumption, animal husbandry output, resident population, per capita domestic water etc.

Keywords: impact factor; Tianjin; water consumption; water utilization structure; sustainable development; water resources management

1. Introduction

As a kind of strategic resources, water resources are not only an important condition of economic and social sustainable development, but also a precondition of improving ecological environment. Water utilization structure is one of the most important elements in water resources and effective water resources management.

Analysis of water utilization structure was prevalent in some scientific literatures. Liu *et al.* [1] qualitatively analyzed the change of water utilization structure of Beijing from 1980 to 2000. Jenerette [2] asserted that the water utilization form depended on population, livestock, climate change, and ecological water supply condition etc. This author judged that there would be continuous water supply crisis in most cities, so attention must be paid to sustainable water resources management. Su *et al.* [3], Ma *et al.* [4] and Zheng *et al.* [5] discussed the water utilization structure of Guanzhong area using information entropy. Lv *et al.* [6] used grey correlation degree to analyze the driving forces of water utilization structure change in Zhengzhou. Chen [7] used information entropy and grey correlation degree to analyze the change of water utilization structure and its impact factors respectively in Xiamen. Furthermore, the impact factors of water utilization structure were chosen by principal component analysis to satisfy the requirement of water resources management. On this basis, Yun *et al.* [8] built a compositional data linear regression model based on partial least-squares regression, and demonstrated the connection coherence between water utilization and industrial structure. Hereafter, Liu *et al.* [9] used a variable stability test, the co-integration and Granger causality test to study the relationship between water utilization structure and industrial sustainable development. Zhai *et al.* [10] not only considered industrial, agricultural and domestic water consumption, but also explored the influence of ecological water consumption on water utilization structure. Indeed, ecological water consumption is very important for sustainable ecological development. Paola *et al.* [11,12] presented a multi-objective approach for the automatic partitioning of a water distribution network into District Metering Areas (DMAs). On this base, Paola *et al.* [13] presented a model for valve setting in water distribution networks (WDNs), with the aim of reducing the level of leakage. Focusing on an African case, Paola *et al.* [14] analyzed the problem of the sustainable design and development of urban storm-water systems in response to the climate change and anthropic modification. Finally, Nunez *et al.* [15] presented a system of two-stage processing for the detection of acoustic emissions and the localization of the sources, which is also instructive.

Water consumption and its impact factors were discussed in some literatures. In general, water consumption can be divided into four categories: industrial, agricultural, domestic and ecological. Marios [16] supposed that the impact factors of water consumption included population growth, sustainable economic development, technical progress, land use pattern, urbanization progress etc. Through logarithmic mean Divisia index Method (LMDI), Liu *et al.* [17] analyzed the industrial water consumption of Anhui province by considering economic scale, industrial structure and water quota. On this basis, Zhang *et al.* [18] added water intensity and industrial water saving effect to those impact factors, and explained the change of industrial water in Anhui Province. Arbues *et al.* [19] calculated the weight of domestic water consumption. Cui *et al.* [20] proposed that the impact factors of domestic water consumption mainly included resident income and water price. Adding drinking water and family population, Xu [21] built a regression model to research the impact factors of domestic water consumption in Beijing.

Above results were meaningful, but the impact factors of water utilization structure should be further perfected. The impact factors from different literatures were complementary. Based on these impact factors and the data we could get (mainly from *Tianjin Statistical Yearbook 2005–2014* [22]), the impact factors were filtered. Besides, in *Tianjin Statistical Yearbook 2005–2014* [22], some indexes did not appear in above literatures, but they had influence on the water consumption of Tianjin. These kinds of indexes also could be used as impact factors. This study took the water consumption of Tianjin from 2004 to 2013 as sample [22]. Tianjin is located in the northeast of North China Plain and in the center of Bohai economic circle. As the largest port city of North China, Tianjin is an important communication hub, directly connecting Beijing to Northeast China, East China and the Pacific Ocean. In this study, the change of water utilization structure in Tianjin was analyzed, and its main impact factors were identified afterwards. These impact factors of water utilization structure are essential for us to conduct effective water resources management and sustainable development in Tianjin.

The study period was from 2004 to 2013. Due to the limitation of water quantity monitoring and resources management abilities, agricultural, industrial, domestic and ecological water consumption data of Tianjin before 2004 was unavailable.

2. Material and Methods

2.1. Research Area

The annual precipitation of Tianjin is 560 mm–720 mm on average, with the precipitation from June to August comprising 75% of total annual precipitation. With the rapid development of economy and society, the water shortage of Tianjin became more and more serious. In fact, water resources had become a key restrictive factor of the sustainable development in Tianjin. After the construction of Luanhe-Tianjin water diversion project, Luanhe River became an important water source for Tianjin. In the past decade, the annual water resources quantity of Tianjin was 1.177 billion m^3, and it was larger in the northern area than in the southern area. From 2000, four times the water supply from

Yellow River to Tianjin were transported to ease the water shortage of Tianjin. After the completion of the first-phase of the middle-line of the South-to-North Water Transfer Project, although the water supply quantity is increased, the water shortage of Tianjin was also severe(Figure 1). Water resources remained a critical issue in Tianjin.

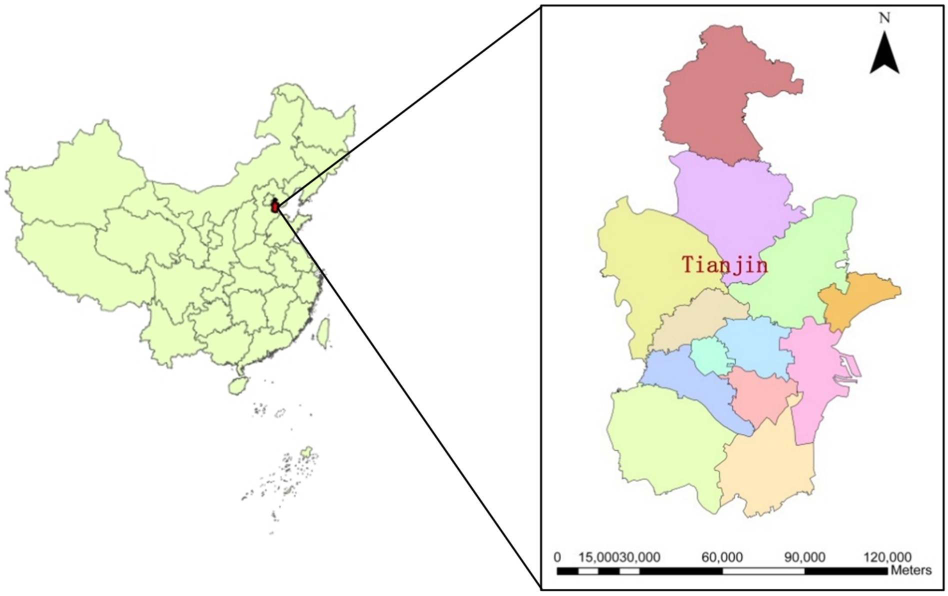

Figure 1. The map of the research area.

2.2. Data Source

Water consumption is affected by many factors. Through literature review, the impact factors of water consumption were summarized as the follows (Table 1).

Table 1. The impact factors of water consumption in literatures.

Water consumption	Impact factor
Agricultural water consumption	canal lining [23], canal facilities [23], water management [23], planting structure adjustment [23], rainfall [23], cultivated area [4,24], climate factors [4] , grain yield [25], water-saving effect [26], water price [26], irrigation area [26,27]
Industrial water consumption	industrial water saving [18], economic scale [17,18], industrial structure [17,18], water intensity [17,18], quota effect [17], population effect [24,28], technology effect [29], water reuse efficiency in industry [24,28], gross industrial output value [24,30], GDP [24], fixed assets investment [24,31]
Domestic water consumption	population [32], water saving model [22], price [32], economy development [32], regional difference [32], municipal infrastructure [32], the lowest temperature [28], the maximum and minimum humidity [32], green coverage of built-up area [24], living space per capita [33], consciousness of water saving [34], family income [21], water price [4,35]
Ecological water consumption	per capita green area [8,36]

Data on water consumption and impact factors were derived from the *2005–2014 Tianjin Statistical Yearbook* [22]. The specific impact factors for agricultural, industrial, domestic, and ecological water consumption are presented in Table 1.The impact factors of agricultural water consumption included cultivated area, effective irrigation area, effective water saving irrigation area, agriculture forestry, animal husbandry, and fishery output value, and rural electricity consumption. The impact factors of industrial water consumption included industrial output value, water consumption of 10,000 Chinese Yuan (CNY) industrial added value, water consumption of 10,000 CNY industrial output value, output value of light industry, heavy industry and high-tech industry. The impact factors of domestic water consumption included resident population, urban per capita income, per capita domestic water consumption. The impact factors of ecological water consumption included per capita green area, garden green area and park area.

3. Analysis Methods

3.1. Information Entropy Anasysis

Entropy is a concept of thermodynamics. Shannon introduced it into information theory, and defined it as information entropy to describe the confusion or disorder degree of system or material [37]. The evolution of water utilization structure has some stages, and they are irreversible. So information entropy could be used to analyze the water utilization structure. This index is useful in water resources sustainable management.

Set the total water consumption equals to Q, and the water consumption is $X_i\,(i = 1, 2, 3 \cdots, n)$. The proportion of each water consumption type is p_i, and $\sum_{i=1}^{n} p_i = 1\,(p_i \neq 0)$. According to Shannon formula, $H = -\sum_{i=1}^{n} p_i \ln p_i$, where H is information entropy. The concept of equilibrium degree is J, and $J = H/H_{\max}$, where $H_{\max}$ is the maximum of information entropy, $H_{\max} = \ln(n)$. With the increase of H, the disorder degree of the system increases, and the structure of the system tends to be more balanced. With the increase of J, the equilibrium degree and stability of the system increase.

3.2. Grey Correlation Analysis Method

A grey system is a system containing both known and unknown information [38,39]. The grey correlation analysis model belongs to one multi-element statistical analysis methods. Based on the sample data, this model descripts the relevance size and order of factors through grey correlation. Since the relationship between water utilization structure and its impact factors is grey, this study used the grey correlation analysis method to analyze these impact factors.

$X_i(t)$ and $X_j(t)$ are the coordinates of the gravity centers of element i and j, respectively. So $\Delta_{i,j}(t) = |X_i(t) - X_j(t)|$ represents the absolute value of the difference between these two coordinates. Set $\Delta(\max)$ and $\Delta(\min)$ are the maximum and minimum values of these differences, then $0 \leqslant \frac{\Delta(\min)}{\Delta(\max)} \leqslant \frac{\Delta_{ij}(t)}{\Delta(\max)} \leqslant 1$. Obviously, with the increase of $\frac{\Delta_{ij}(t)}{\Delta(\max)}$, the consistency of change between (X_i) and (X_j) becomes weaker. In order to limit the standardized data between 0 and 1, the value could be taken as $\frac{\Delta(\min)/\Delta(\max)}{\Delta_{ij}(t)/\Delta(\max)}$.

For convenience, the grey correlation degree was classified into three groups: 0–0.60 implies weak correlation degree, 0.60–0.80 implies moderate correlation degree, 0.80–1.0 implies strong correlation degree [40].

4. The Water Consumption and Its Impact Factors

The total water consumption of Tianjin increased from 2.206 billion m^3 in 2004 to 2.337 billion m^3 in 2007. Its annual growth rate was 1.94% on average. The total water consumption of Tianjin in 2008 and 2009 fluctuated slightly. From 2010 to 2013, the annual growth rate was 1.85% on average (Figure 2).

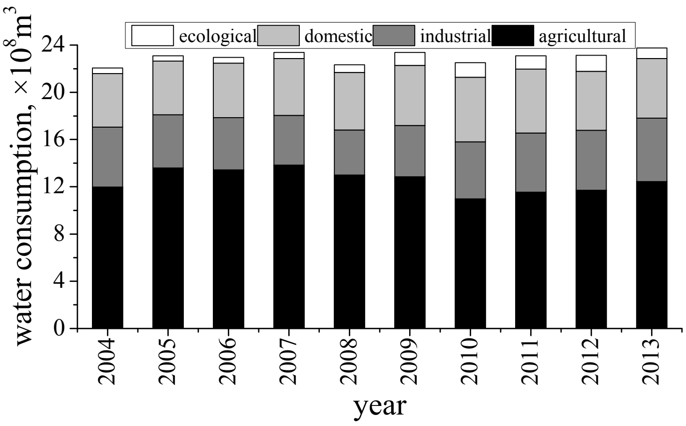

Figure 2. The water consumption of Tianjin from 2004 to 2013.

4.1. Agricultural Water Consumption

From 2004 to 2013, the agricultural water consumption of Tianjin accounted for 48%–59% of the total water consumption, and it was the largest water user in Tianjin. The change of agricultural water consumption could be divided into three stages. From 2004 to 2007, it increased from 1.198 billion m^3 to 1.384 billion m^3, and the annual growth rate was 4.93% on average; after 2007, it decreased to 1.097 billion m^3, and the annual growth rate was 7.45% on average; hereafter, it increased slightly.

The agricultural water consumption changed because the decrease of cultivated area and effective irrigation area and the increase of efficient water saving irrigation area. Indeed, the cultivated area of Tianjin decreased from 0.42 million hm^2 in 2004 to 0.39 million hm^2 in 2013, and its annual change rate was −0.63% on average; the effective irrigation area decreased from 0.35 million hm^2 in 2004 to 0.31 million hm^2 in 2013, and its annual change rate was −1.5% on average; efficient water saving irrigation area increased from 0.19 million hm^2 in 2004 to 0.29 million hm^2 in 2013, and its annual growth rate was 5.16% on average. In addition, the agricultural electricity consumption increased from 4.84 billion kWh in 2004 to 6.92 billion kWh in 2013, and its annual growth rate was 4.05% on average; the output value of primary industry increased from 22.14 billion CNY in 2004 to 40.20 billion CNY in 2013, and its annual growth rate was 6.86% on average.

Fishery output value had weak correlation with agricultural water consumption. Other impact factors had moderate correlation with agricultural water consumption (Table 2). It appeared that the adjustment of agricultural structure and the improvement of water saving irrigation technology influenced the agricultural water consumption. In these years, Tianjin City conducted the strategic layout of taking planting as a foundation and taking breeding industry as a sustainable development emphases. With the promotion of water saving irrigation technology, unreasonable irrigation methods were eliminated. On this basis, supposing that, the agricultural water of Tianjin developed in a sustainable direction.

Table 2. Grey correlation degree between the agricultural water and its impact factors in Tianjin.

	Correlation Degree		**Correlation Degree**
Cultivated area	0.7357	Forestry output value	0.6921
Effective water saving irrigation area	0.6571	Animal husbandry output value	0.7087
Effective irrigation area	0.6699	Fishery output value	0.4901
Agricultural output value	0.6642	Rural electricity consumption	0.7071

4.2. Industrial Water Consumption

From 2004 to 2013, the industrial water consumption of Tianjin accounted for 17%–23% of total water consumption. Its change could be divided into two stages: from 2004 to 2008, it reduced from 0.507 billion m^3 to 3.81 billion m^3, and its annual change rate was 6.89% on average; from 2008 to 2013, it increased from 0.381 billion m^3 to 0.537 billion m^3, and its annual growth rate was 7.11% on average.

The change of industrial water consumption was significantly influenced by the policy and regulation. In order to achieve sustainable water resources management, Tianjin City proposed "regulations on water saving of Tianjin" in 2002, which was the first local regulation on water saving in China. From 2004 to 2013, the industrial output value of Tianjin increased from 168.59 billion CNY to 727.55 billion CNY, while the water consumption of 10,000 CNY industrial output value decreased from 30.07 m^3 to 7.38 m^3. The water saving technology was improved and the industrial structure was adjusted. Consequently, from 2004 to 2008, the industrial water consumption decreased. However, in 2009, the administrative division of the New Coastal Region of Tianjin was reformed. The rapid development of the New Coastal Region of Tianjin accelerated the industrial economic development of Tianjin. At this time, the industrial output value of Tianjin was 398.78 billion CNY, and the New Coastal Region of Tianjin accounted for only 9.2% of Tianjin; in 2013, the industrial output value of Tianjin was 727.55 billion CNY, and the New Coastal Region of Tianjin accounted for 70.6% of Tianjin. The supernormal development of the New Coastal Region of Tianjin was an important explanation for the increase of the industrial water consumption of Tianjin after 2008. As a large industrial city, controlling total water consumption while ensuring the economic development was a challenge for Tianjin.

All of the impact factors had moderate correlation with the industrial water consumption of Tianjin (Table 3). Thus, the industrial economic quality had a significant influence on total water consumption in Tianjin. This finding suggested that improving industrial economic quality would promote the improvement of water resources management.

Table 3. Grey correlation degree between the industrial water and its impact factors in Tianjin.

	Industrial output value	**Water consumption of ten thousand CNY industrial output value**	**Water consumption of ten thousand CNY industrial added value**	**Light industry output value**	**Heavy industry output value**	**High technology industry output value**
Correlation degree	0.6768	0.7144	0.7520	0.7056	0.6645	0.6786

4.3. Domestic Water Consumption

From 2004 to 2013, the domestic water consumption of Tianjin accounted for 20%–25% of the total water consumption. The change of the domestic water consumption could be divided into two stages: In the first stage, the domestic water consumption increased steadily, while in the second stage, it reduced with fluctuation. Specifically, from 2004 to 2010, it increased from 0.453 billion m^3 in 2004 to 0.548 billion m^3 in 2010, and its annual growth rate was 3.22% on average; and from 2010 to 2013, it decreased from 0.548 billion m^3 to 0.515 billion m^3, and its annual change rate was 2.69% on average.

The basic explanation for the change of the domestic water consumption of Tianjin was population growth. The resident population increased from 10.24 million in 2004 to 14.72 million in 2013, and the annual growth rate was 4.12% on average. With the simultaneous improvement in living standard, per capita domestic water consumption increased from 123.6 m^3 in 2005 to 142.34m^3 in 2013.

All of the impact factors had moderate correlation with the domestic water consumption of Tianjin (Table 4). With the adjustment of fertility policy and the improvement of income level, the domestic water consumption of Tianjin would be increased in the future. Green lifestyle could be very important in forming sustainable water resources management.

Table 4. Grey correlation degree between the domestic water and its impact factors in Tianjin.

	Resident population	Urban per capita income	Per capita domestic water consumption
Correlation degree	0.7375	0.6898	0.6806

4.4. Ecological Water Consumption

Given the importance of ecological environment protection and sustainability, the ecological water consumption of Tianjin was also studied. It increased from 48 million m^3 in 2004 to 136 million m^3 in 2012, and its annual growth rate was 13.9% on average; in 2013, it reduced by 33.8%. Certain factors may explain this change in ecological water consumption. For example, the per capita green area of Tianjin increased from 13.87 m^2 in 2004 to 15.76 m^2 in 2013, and its growth rate was 13.6% on average; the garden green area increased from 14238.1 hm^2 in 2004 to 23916 hm^2 in 2013, and its annual growth rate was 5.93% on average; the park area increased from 2424 hm^2 in 2004 to 7279 hm^2 in 2013, and its annual growth rate was 13% on average.

Garden green area had a moderate correlation degree with the ecological water consumption. Park area had a weak correlation degree with the ecological water consumption (Table 5). Ecological environment is essential for sustainable development.

Table 5. Grey correlation degree between the ecological water and its impact factors in Tianjin.

	Per capita green area	Garden green area	Park area
Correlation degree	0.4946	0.7052	0.6414

5. The Evolution of Water Utilization Structure and Its Impact Factors

5.1. Water Utilization Structure Analysis

The change of water utilization structure of Tianjin could be divided into two stages. In the first stage, the information entropy increased from 1.078 in 2004 to 1.183 in 2010, and its annual average rate was 1.56%. Through relative literatures, if the annual average rate was larger than 2%, the change of information entropy was considered to be obvious or rapid; otherwise, it was considered to be inconspicuous or slow [3,5,7,41]. Therefore, when the information entropy increased from 1.078 to 1.183, it increased slowly. The water utilization structure of Tianjin tended to be more disordered and balanced. This result implied that that the dominance of a single water consumption type decreased generally. The water utilization structure of Tianjin developed in a sustainable direction. It also demonstrated that the water resources management tended to be more sustainable. In the second stage, the information entropy fluctuated between 1.128 and 1.165. The relatively high information entropy meant that the water utilization structure of Tianjin was relatively mature, and influence of single factor reduced continuously (Figure 3). Similar results could be obtained by considering the equilibrium degree.

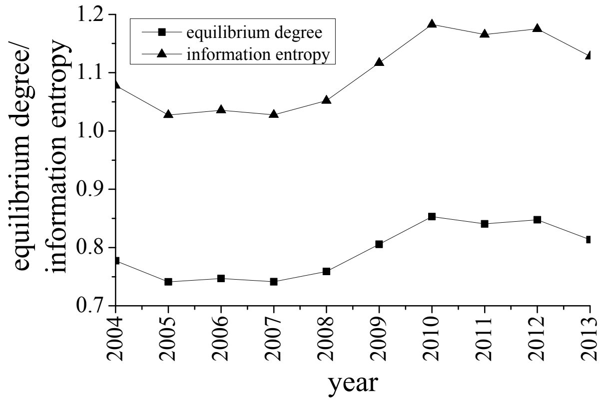

Figure 3. The change of equilibrium degree and information entropy of water utilization structure in Tianjin from 2004 to 2013.

5.2. The Impact Factors Analysis of Water Utilization Structure

Rejecting the impact factors whose correlation degree was less than 0.6, other impact factors were used to do correlation analysis with the information entropy of water utilization structure. Besides, considering industrial structure had obvious influence on water utilization structure (Table 1), relative indexes were added. The information entropy of the water utilization structure was taken as reference sequence X_0, the originally selected impact factors included: the proportion of primary industry X_1, the proportion of secondary industry X_2, the proportion of tertiary industry X_3, cultivated area X_4, effective irrigation area X_5, effective water saving irrigation area X_6, agricultural output value X_7, forestry output value X_8, animal husbandry output value X_9, rural electricity consumption X_{10}, water consumption of 10,000 CNY industrial added value X_{11}, water consumption of 10,000 CNY industrial output value X_{12}, light industry output value X_{13}, heavy industry output value X_{14}, high technology industry output value X_{15}, resident population X_{16}, urban per capita income X_{17}, per capita domestic water consumption X_{18}, garden green area X_{19}, park area X_{20}.

After calculation, the correlation degrees of the impact factors were: $X_{10}>X_4>X_{19}>X_7>X_{12}>X_{13}>X_{11}>X_{16}>X_{14}>X_9>0.7>X_{20}>X_{15}>X_1>X_{17}>X_{18}>X_5>X_6>X_8>X_2>X_3>0.6$. They all had moderate correlation with the water utilization structure of Tianjin (Table 6).

Table 6. Grey correlation degree between the water utilization structure and its impact factors in Tianjin.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Correlation degree	0.6787	0.6326	0.6295	0.7478	0.6636	0.6420	0.7434	0.6417	0.7024	0.7726
	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}
Correlation degree	0.7201	0.7383	0.7301	0.7126	0.6804	0.7151	0.6690	0.6653	0.7446	0.6934

6. Conclusions

Tianjin has an important position in China and an undeniably good foundation of water quantity monitoring in China, making it an ideal study site. Through information entropy analysis and grey correlation analysis method, the changing process of water consumption was studied, thereafter the evolution law and the impact factors of the water utilization structure were discussed. Compared with previous studies, the impact factors of the water utilization structure in this study were more comprehensive. The results of this study were meaningful for adjusting water consumption and optimizing water utilization. The water utilization structure reflected the level of water resources management sustainable development to some extent.

From 2004 to 2010, the water utilization structure of Tianjin tended to be disordered and balanced. It meant that the dominance of a single water consumption type decreased and the equilibrium degree increased generally. In general, the water utilization structure of Tianjin developed in a sustainable direction. It also demonstrated that the water resources management tended to be more sustainable. From 2011 to 2013, the relatively high information entropy implied that the water utilization structure of Tianjin was relatively mature, and influence of single factors reduced continuously.

From 2004 to 2013, rural electricity consumption, cultivated area, garden green area, agricultural output value, water consumption of 10,000 CNY industrial output value, light industry output value, per capita green area, per capita green area, water consumption of 10,000 CNY industrial added value, resident population, heavy industry value and animal husbandry output value had strong correlation with the water utilization structure of Tianjin. These results could be used to adjust water consumption and further optimize water utilization structure.

In the future, if the water consumption data is plentiful and the related technologies are mature, the water utilization structure could be predicted accurately, and its impact factors will be identified effectively.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, B.Q.; Yao, Z.J.; Gao, Y.C. Trend and driving forces of water consumed structure changes in Beijing. *Resour. Sci.* **2003**, *25*, 38–43. (In Chinese)
2. Jenerette, G.D. A global perspective on changing sustainable urban water supplies. *Glob. Planet. Chang.* **2006**, *50*, 202–211. [CrossRef]
3. Su, X.L.; Zhao, C.; Ma, L.H. Water consumed structure evolvement and its driving forces for Guanzhong Region in the past 20 years. *J. Irrig. Drain.* **2008**, *27*, 71–73. (In Chinese)
4. Ma, L.H.; Kang, S.Z.; Su, X.L. Study on evolution and its driving forces of water utilization structure of Shiyang River Basin in northwest arid areas. *Agric. Res. Arid Areas* **2008**, *26*, 125–130. (In Chinese)
5. Zheng, A.Q.; Wang, W.K.; Duan, L. Water consumption structure evolvement and its driving forces for Guanzhong Basin. *J. Arid Land Resour. Environ.* **2011**, *25*, 75–79. (In Chinese)
6. Lv, C.M.; Wu, Z.N.; Hu, C.H. Grey relational degree analysis on the major driving forces of water use structure. *Water Sav. Irrig.* **2008**, *2*, 39–41. (In Chinese)
7. Chen, X.F. Analysis of grey relation degree based on water utilization evolution and driving force of information entropy in Xiamen. *J. Water Resour. Water Eng.* **2013**, *24*, 188–191. (In Chinese)
8. Yun, Y.; Zou, Z.H.; Wang, H.W. A regression model based on the compositional data of Beijing's water consumed structure and industrial structure. *Syst. Eng.* **2008**, *26*, 67–71. (In Chinese)
9. Liu, X.X.; Xie, J.C. The interactive relationship between water consumption structure and industrial structure of Shanxi Province. *Syst. Eng.* **2011**, *29*, 45–51. (In Chinese)
10. Zhai, Y.Z.; Wang, J.S.; Zheng, J.Q.; Huan, H. Evolution and driving forces of water consumed structure in Beijng during the past 30 years. *J. Nat. Resour.* **2011**, *26*, 635–643. (In Chinese)
11. Paola, F.D.; Fontana, N.; Galdiero, E.; Giugni, M.; Savic, D.; Uberti, G.S. Automatic multi-objective sectorization of a water distribution network. *Procedia Eng.* **2014**, *89*, 1200–1207. [CrossRef]
12. Paola, F.D.; Fontana, N.; Galdiero, E.; Giugni, M.; Uberti, G.S.; Vitaletti, M. Optimal design of district metered areas in water distribution networks. *Procedia Eng.* **2014**, *70*, 449–457. [CrossRef]
13. Paola, F.D.; Galdiero, E.; Giugni, M. A jazz-based approach for optimal setting of pressure reducing valves in water distribution networks. *Eng. Optim.* **2015**. [CrossRef]

14. Paola, F.D.; Galdiero, E.; Giugni, M.; Pugliese, F. Sustainable development of storm-water systems in African cities considering climate change. *Procedia Eng.* **2015**, *119*, 1181–1191. [CrossRef]
15. Nunez, B.; Roman, J.E.P.; Souto, J.A.G. Decision support system for the optimal design of district metered areas. *J. Hydroinf.* **2015**. [CrossRef]
16. Marios, S. Global and regional water availability and demand prospects for the future. *Nat. Resour. Res.* **2004**, *13*, 61–75.
17. Liu, C.; Bai, M.G. Change in industrial water use in Anhui Province based on LMDI. *Resour. Sci.* **2012**, *34*, 2299–2305. (In Chinese).
18. Zhang, L.B.; Xu, Y.J.; Jin, J.L.; Wu, C.G. Analysis of influence factors of regional industry water use in Anhui Province. *J. Hydraulic Eng.* **2014**, *45*, 837–843. (In Chinese)
19. Arbues, F.; Barberan, R.; Villanua, I. Price impact on urban residential water demand: A dynamic panel data approach. *Water Resour. Res.* **2004**, *40*, 1–9. [CrossRef]
20. Cui, H.S.; Deng, Y.Q. Factors influencing residential water consumption. *Water Resour. Prot.* **2009**, *25*, 83–85. (In Chinese)
21. Xu, H. *Investigation on Influencing Factors of Domestic Water Use in Beijing*; Capital Normal University: Beijing, China, 2012. (In Chinese)
22. Tianjin Municipal Bureau of Statistics. *Tianjin Statistical Yearbook 2005–2014*; China Statistic Press: Beijing, China, 2005–2014. (In Chinese)
23. Zhao, L.R.; Wu, J.W.; Yang, X.; Huang, Z.Q.; Li, H.Q. Analysis of influence factors of irrigation water quantity of Hetao Irrigation District based on analysis of variance. *Water Sav. Irrig.* **2009**, *7*, 1–3. (In Chinese)
24. Liu, Z.X. *Analysis on Water Demand Structure Change and Water Consumption Forecasting in Baotou*; Northwest A & F University: Xi'an, China, 2013. (In Chinese)
25. Xie, H.T. *The Research of Water Resources Utilization and Its Influencing Factor Analysis in Hunan Province*; Hunan University: Hunan, China, 2011. (In Chinese)
26. Qin, H.Y. *Performance Evaluation and Influence Factor Analysis of Agricultural Water of Ganzhou District: A Perspective of Farmer Water User Associations*; Lanzhou University: Lanzhou, China, 2014. (In Chinese)
27. Harun, R.; Muresan, I.C.; Arion, F.H. Analysis of factors that influence the willingness to pay for irrigation water in the Kurdistan Regional Government, Iraq. *Sustainability* **2015**, *7*, 9574–9586. [CrossRef]
28. Mai, Z.Y.; He, Z.J.; Wang, X.H. Urban hourly water demand prediction based on principal factors analysis. *J. Zhejiang Univ. (Eng. Sci.)* **2012**, *46*, 1968–1974. (In Chinese)
29. Liu, Y.F.; Kong, W. Analysis of industry water utilization change in Beijing based on factor decomposition model. *Water Resour. Power* **2013**, *31*, 26–29. (In Chinese)
30. Wu, F.; Zhan, J.Y.; Zhang, Q. Evaluating impacts of industrial transformation on water consumption in the Heihe River Basin of Northwest China. *Sustainability* **2014**, *6*, 8283–8296. [CrossRef]
31. Shi, Q.L.; Chen, S.Y.; Shi, C.C. The impact of industrial transformation on water use efficiency in Northwest Region of China. *Sustainability* **2015**, *7*, 56–74. [CrossRef]
32. Sun, Y.; Xu, Z.X. Impact factors classification urban water consumption forecast and priority weight analysis for forecasting target. *Energy Environ. Prot. (S1)* **2008**, *34*, 114–117. (In Chinese)
33. Tian, S.Y.; Li, X.C.; Yang, B.Z.; Qiu, Y.Q.; Wang, C.Y.; Du, J.K. Xi'an urban residents living water demand factors analysis. *China Rural Water Hydropower* **2014**, *2*, 35–37. (In Chinese)
34. Cheng, Z.L.; Zuo, J.L.; Li, H.; Xu, Y.T.; Wang, L.; Wang, Z.P. Analysis of affecting factors for water consumption of new rural residents. *Water Sav. Irrig.* **2011**, *10*, 51–59. (In Chinese)
35. Ma, D.C.; Xian, C.F.; Zhang, J. The evaluation of water footprints and sustainable water utilization in Beijing. *Sustainability* **2015**, *7*, 13206–13221. [CrossRef]
36. Yan, J.J.; Sha, J.H.; Chu, X. Dynamic evaluation of water quality improvement based on effective utilization of stockbreeding biomass resource. *Sustainability* **2014**, *6*, 8218–8236. [CrossRef]
37. Shannon, C.E. A mathematical theory of communication. *Mob. Comput. Commun. Rev.* **1948**, *5*, 3–55. [CrossRef]
38. Zhang, S.L.; Zhang, G.L. Comparison of grey correlation calculation methods and its problem. *Syst. Eng.* **1996**, *14*, 45–49. (In Chinese)
39. Deng, J.L. *Foundation of Grey System*; Huazhong University of Science and Technology: Wuhan, China, 2002; pp. 122–209. (In Chinese)

40. Fan, J.G. The grey analysis on grain output and its main input elements in Shaanxi Province from 1983 to 2004. *Agric. Res. Arid Areas* **2007**, *25*, 209–212. (In Chinese)
41. Lei, H.; Zhang, X. Anslysis on water use structure change and its driving forces during last 10 years in Shaanxi Province. *J. Water Reour. Water Eng.* **2012**, *23*, 125–128. (In Chinese)