Construction of an evaluation index system of water resources bearing capacity: An empirical study in Xi'an, China

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Abstract. In this paper, a comprehensive evaluation of the water resources bearing capacity of Xi'an is performed. By constructing a comprehensive evaluation index system of the water resources bearing capacity that included water resources, economy, society, and ecological environment, we empirically studied the dynamic change and regional differences of the water resources bearing capacities of Xi'an districts through the TOPSIS method (Technique for Order Preference by Similarity to an Ideal Solution). Results show that the water resources bearing capacity of Xi'an significantly increased over time, and the contributions of the subsystems from high to low are as follows: water resources subsystem, social subsystem, ecological subsystem, and economic subsystem. Furthermore, there are large differences between the water resources bearing capacities of the different districts in Xi'an. The water resources bearing capacities from high to low are urban areas, Huxian, Zhouzhi, Gaoling, and Lantian. Overall, the water resources bearing capacity of Xi'an is still at a the lower level, which is highly related to the scarcity of water resources, population pressure, insufficient water saving consciousness, irrational industrial structure, low water-use efficiency, and so on.

1. Introduction

The global water crisis has become one of the greatest challenges of the 21st century. Since the 1980s, with the rapid development of China's economy, the water shortage and water environment have become increasingly serious, which has, in turn, created a significant bottleneck that restricts the development of the Chinese economy. In 2002, the Chinese government promulgated and implemented the water law of the People's Republic of China and subsequently developed a series of regulations and policies aimed at addressing water shortage issue and environmental destruction. Such developments have important practical significance and strategic significance to the promotion of sustainable utilization of water resources in China.

In the inland northwest region, the water resources of Xi'an are inadequate and unevenly distributed. Since the west became further developed, the central economic regions have transferred to the west. Furthermore, the population growth of Xi'an is continuing to increase; thus, the economic water consumption and residents' living water consumption increase every year, evidencing the serious connection between urban development and available water supply. Statistical data show that in 2014 the total water resource of Xi'an is 21.92 billion cubic meters, and the per capita water resource is only 268.86 cubic meters, which only accounts for 1/4.2 of the per capita water resources of the Shaanxi Province [1]. At present, both the average annual precipitation and per capita surface water resource of Xi'an are far below the internationally recognized critical value. Inadequate water resources, serious water pollution, inadequate sewage disposal facilities, and other factors cause Xi'an to be a city with one of the worst water scarcities. In order to achieve a sustainable utilization of water resources, the Xi'an government has increased its investment in water conservancy construction and water environmental governance since the 13th five-year plan. In December 2001, the main project of the Heihe Water Diversion was completed. In 2002, the Xi'an government publicized the "Xi'an water resources management approaches", giving priority to the development of water conservancy construction for people's livelihood. Thereafter, Xi'an government successively promulgated a series of local laws and regulations, such as "Xi'an water resources management ordinance" and "Measures for the protection and management of Heihe River".

2. Literature review

The utilization and protection of water resources have attracted the attention of the Xi'an government as well as many scholars. Many scholars have defined water resources bearing capacity; however, water resources carrying capacity is still a concept with a fuzzy extension and connotation. In this paper, with foreseeable technical, economic, and social development levels, based on the principle of sustainable development, we consider water resources carrying capacity to be the maximum supporting capacity of water resources for the social and economic development of the region after a reasonable optimization disposition in a specific historical stage of development.

Internationally, Falkenmark [2] and Bable [3] used the system dynamics method to calculate the usage of water resources in some developing countries and analyzed water resources bearing capacity, thereby laying the foundation for the quantitative study of water resources carrying capacity. With water supply, drainage, sewage, and other indicators, Joardor [4] built a water resources bearing capacity evaluation system and carried out an empirical study on the water resources bearing capacity in India City, believing that the assessment of urban water supply facilities would aid in determining the potential of the city's sustainable growth. Harris and Kennedy [5] focused on the support ability of water resources in agricultural areas worldwide. They consider the water resources bearing capacity and land bearing capacity to be important criterions for regional sustainable development. Rijsberman [6] studied the sustainable development of the Holland urban water system and considered water resource to be an important condition for a city's healthy and rational operation and scientific management. Varis O and Vakkilainen P [7] conducted a comparative analysis of the social economic situation of the Yangtze River Basin and its water environment bearing capacity, thereby revealing the water resources management problems faced by China in the 1980s and 1990s.

Domestically, Wang C [8] used the principal component analysis method to evaluate the water

resources bearing capacity of Ordos City and found its water resources bearing capacity to be relatively small. Xie Y [9] studied the water resources bearing capacity of Yulin City through the analytic hierarchy process and "Mode and Sum", and it was found that its water resources bearing capacity has been declining over time. Shao J [10] studied the effective management and sustainable utilization of water resources in Xi'an and claimed that water scarcity has become an important factor restricting the economic development of Xi'an. Based on the natural--artificial two elements model and through the construction of the water resources bearing capacity evaluation system, Li G [11] used the multi-level fuzzy comprehensive evaluation method to study the water resources bearing capacity of Hubei, and it was found that the water resources bearing capacity of Hubei has great potential. Based on the complex system theory, Duan X G and Luan F F [12] used the fuzzy comprehensive evaluation model to evaluate the current situation of the Xinjiang water resources bearing capacity, and they proposed that the development and utilization of water resources in Xinjiang has a certain scale. Wang C J [13] comprehensively evaluated the relative population bearing capacity and the relative economy bearing capacity of resources of the Tarim River Basin and provided some corresponding countermeasures from the aspect of the sustainable utilization of water resources.

3. Study objectives

Based upon the above research, we adopted a compound system theory of "water resources--social economy-ecological environment". By applying the TOPSIS comprehensive evaluation method, we evaluated and analyzed the water resources bearing capacity of Xi'an and explored reasonable methods for the exploitation and utilization of water resources. The results of this paper have great practical significance on the improvement of the water resources bearing capacity of Xi'an. Additionally, this study will aid in the sustainable development of the economy and water resources as well as contribute to the urban ecosystem.

4. Method and material

4.1. Construction of evaluation index system

A comprehensive evaluation of water resources bearing capacity involves taking into consideration the population, economy, society, ecological environment, and so on. Following the guiding ideology and principles in the construction of the evaluation index system, we constructed the evaluation index system of the water resources bearing capacity from three levels: the target layer, criterion layer, and index layer. The target layer is the water resources bearing capacity under the framework of sustainable development and is the ultimate goal of the evaluation index system, which reflects the overall allocation of water resources. The criterion layer, as a subdivision of the target layer, can serve as a criterion for the comprehensive evaluation, and it consists of four aspects: the water resources subsystem, economic subsystem, social subsystem, and ecological subsystem. The index layer is the concrete manifestation of each criterion layer and is the basis of the evaluation index system. The economic meaning and calculation method of the indexes for all levels are shown in table 1.

The original data for the evaluation index are from the "Xi'an statistical yearbook", "Shaanxi statistical yearbook", "Shaanxi Provincial Water Resources Bulletin", "Shaanxi Environmental Statistics Bulletin" and "Shaanxi Province Environmental Status Bulletin.

Table 1. Comprehensive evaluation index system of the water resources bearing capacity in Xi'an.

Target Layer	Criterion Layer	Index Name	Calculation Method	Meaning	Category
water resources bearing capacity (A)	water resources subsystem (B$_1$)	per capita water resources C$_1$	total water resources/total population	the situation of per capita water resources	positive
		utilization rate of water resources C$_2$	total water supply/total water resources	the development and utilization of water resources	negative
		water producing module C$_3$	total water resources/urban area	the dynamic change of water resources	positive
		annual water supply	statistical data	the situation of urban water supply	positive
		water supply module C$_5$	total water supply/urban area	water supply capacity of water resources	negative
		surface water resources proportion C$_6$	surface water resources/total water resources	the distribution of water resources	positive
	economic subsystem (B$_2$)	GDP C$_7$	statistical data	the level of urban economic development	positive
		GDP growth rate C$_8$	GDP growth amount/GDP	the driving forces of urban economic development	positive
		water resource per 10,000 Yuan GDP C$_9$	total water resources/GDP	economic benefits of water resources utilization	negative
		tertiary industry proportion C$_{10}$	tertiary industry GDP/GDP	the optimization of economic structure	positive
		water use per 10,000 Yuan industry gross production value C$_{11}$	total industrial water consumption/industrial value added	the efficiency of industrial water	negative
		repeated use rate of industrial water C$_{12}$	the repeated industrial water/total industrial water consumption	the efficiency of industrial water reuse	positive
	social subsystem (B$_3$)	population density C$_{13}$	total population/region area	the distribution density of population	negative
		total population C$_{14}$	statistical data	the size of the population	negative

	urbanization rate C_{15}	urban population/total population	the degree of urbanization	positive
	natural population growth rate C_{16}	natural population growth /annual average total population	the natural growth of the population trend	negative
	urban per capita living water consumption C_{17}	urban living water consumption/total urban population	per capita water consumption of urban residents	negative
	urban living water consumption C_{18}	statistical data	the dynamic changes of living water consumption	negative
ecological subsystem (B_4)	forest coverage C_{19}	forest area/city area	the degree of urban greening	positive
	Built-up areas green coverage rate C_{20}	greening area/city area	the degree of built-up areas greening	positive
	per capita public green area C_{21}	total garden green area/ population of non-agriculture	per capita public green area	positive
	per capita garden green area C_{22}	total garden green area/total population	per capita garden green area	positive
	urban wastewater treatment capacity C_{23}	statistical data	city's wastewater treatment capacity	positive
	urban sewage treatment rate C_{24}	wastewater treatment amount/total amount of waste water	the situation of urban wastewater treatment	positive

4.2. Evaluation methods

At present, there are no unified and mature research methods on the water resources bearing capacity either domestically or abroad due to its wide range and complex content. Scholars have adopted different methods for studying the water resources bearing capacity according to their research purpose and data characteristics. Integrated water resources management (IWRM), water impact index, and technique for order preference by similarity to an ideal solution (TOPSIS) can be used to evaluate the bearing capacity of water resources in a particular area. IWRM focuses on the sustainable utilization of water resources, emphasizes the integrated management of water and soil resources and other related resources, and attaches importance to coordination and public participation. It is considered to be an effective and sustainable solution to the problem of water resources, and it is highly praised by the international water community [14]. By setting up the framework of IWRM implementation, we can evaluate and analyze the current situation of water resources management in a specific country or region. However, the evaluation indicators that reflect the key areas of the implement environment, management system, and management tools are primarily abstract and

qualitative indicators. Thus, it is necessary to combine qualitative analysis with quantitative methods, which is too subjective. The Water Impact Index is a tool developed by Veolia to measure the impact of activities on a local water resource. It integrates the issues of volume, scarcity, and quality into a single indicator that assesses the relative magnitude of potential impacts to freshwater availability generated by a human activity. The Water Impact Index has the potential to serve a number of purposes, including screening and evaluating the usage of water, decision support, and communication. However, the Water Impact Index does not provide a comprehensive assessment of water-related environmental impacts. TOPSIS, first proposed by Hwang C L and Yoon L S [15], is a method of system engineering for multi-objective-decision-making with advantages such as no strict limits to the data distribution, the sample quantity, and the number of indexes. Moreover, TOPSIS has is characterized by scientific evaluation, intuitive geometric meaning, small information distortion, and so on [16]. The basic idea of TOPSIS is to first define the positive ideal solution and the negative ideal solution for the evaluation object and then identify the solution from among the feasible schemes that is closest to the positive ideal solution and farthest away from the negative ideal solution. This solution is the satisfactory solution. Considering the advantages and disadvantages of various methods, we adopted the TOPSIS comprehensive evaluation method, that is, the ideal solution method. The main steps of the TOPSIS method are as follows:

- Construct the evaluation matrix. Assuming there are N evaluation units and k evaluation indexes, the original data matrix is

$$A = (a_{ij})_{n \times k} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1k} \\ a_{21} & a_{22} & \dots & a_{2k} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nk} \end{bmatrix}_{n \times k} \tag{1}$$

- Normalize the original data matrix to eliminate the influence of dimension as in equation (2), then construct the normalized decision matrix Z as in equation (3).

$$z_{ij} = a_{ij} \left(\sum_{i=1}^{n} a_{ij}^2 \right)^{-\frac{1}{2}}, \quad i = 1, 2, \dots, n; \quad j = 1, 2, \dots, k \tag{2}$$

$$Z = (z_{ij})_{n \times k} = \begin{bmatrix} z_{11} & z_{12} & \dots & z_{1k} \\ z_{21} & z_{22} & \dots & z_{2k} \\ \dots & \dots & \dots & \dots \\ z_{n1} & z_{n2} & \dots & z_{nk} \end{bmatrix}_{n \times k} \tag{3}$$

- Define the positive ideal solution Z+ and the negative ideal solution Z-.

$$z^+ = (z_1^+, z_2^+, \dots, z_k^+), \quad z^- = (z-, z_2^-, \dots, z_k^-) \tag{4}$$

- Calculate the distance between the i evaluation unit and the positive ideal solution D_i^+ and the distance between the i evaluation unit and the negative ideal solution D_i^-.

$$D_i^+ = \sqrt{\sum_{j=1}^{k}(z_{ij} - z_j^+)^2}, \quad D_i^- = \sqrt{\sum_{j=1}^{k}(z_{ij} - z_j^-)^2} \tag{5}$$

- Calculate the relative approach degree between the i evaluation unit and the ideal solution C_i.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{6}$$

Sort the relative approach degree (C_i) by numeric value. The larger the value is, the closer it is to the ideal state. Accordingly, a larger value also corresponds to better evaluation results and a more secure water resources bearing system. Conversely, the smaller the value is, the less secure the water resources bearing system is. When the value is 1, all the indexes of the water resources bearing system are optimal, and the system is in the ideal condition.

5. Results and discussion

5.1. Longitudinal evaluation and analysis of the water resources bearing capacity of Xi'an
Following the principles and procedures of the TOPSIS comprehensive evaluation method, and based on the normalized data, we evaluated the water resources bearing capacity of Xi'an in 2000-2014. The larger the value is, the stronger the water resources bearing capacity is. Conversely, the smaller the value is, the weaker the water resources bearing capacity is. The evaluation results are shown in table 2.

- The target layer evaluation results show that the water resources bearing capacity of Xi'an during the research period increased with fluctuation, and the evaluation value increased from 0.2511 in 2000 to 0.2953 in 2014. More specifically, the comprehensive evaluation value of the water resources bearing capacity decreased from 0.511 in 2000 to 0.1692 in 2008 and then increased to 0.8512 in 2009, before decreasing to 0.2953 in 2014. The water resources bearing capacity reached a maximum value of 0.8512 in 2009 and a minimum value of 0.1490 in 2007. The contribution of the water resources subsystem is the largest with a mean value of 0.4998, followed by the social subsystem, ecological subsystem, and economic subsystem. Overall, the evaluation values of the four subsystems initially increased and then decreased. Since the 20th century, Xi'an has gradually increased its investment in ecological and environmental governance, and the per capita green area has increased year by year. In 2000, the per capita green area was only 5.98%; however, by 2014, it had increased to 23.20% with an average annual increase of 3.9 percentage points [17]. After the promulgation of "The People's Republic of China Water Law" (2002), the Xi'an government published the "Xi'an water resources management approaches, 2002" and revised it in 2004. In May 2002, the Xi'an

government established the Xi'an water authority in order to intensify protection of water resources. Since then, the government has successively implemented a series of policy measures, such as the "sustainable utilization plan of water resources in Xi'an" and the "water saving water plan of Xi'an". The government's work has caused the management and protection of water resources to be both a scientific and institutionalized venture. Meanwhile, the government attaches importance to the popularization of new technologies and equipment in industry that are capable of conserving water. Additionally, they have limited high water consumption projects in order to improve wastewater treatment and the reuse rate of industrial water. These policy measures have played a positive role in improving the water resources bearing capacity of Xi'an.

Table 2. Evaluation results of water resources bearing capacity of Xi'an in 2000-2014.

Year	Comprehensive bearing capacity (A)	Water resources subsystem (B₁)	Economic subsystem (B₂)	Social subsystem (B₃)	Ecological subsystem (B₄)
2000	0.2511	0.4514	0.2022	0.8056	0.2624
2001	0.2680	0.4545	0.2001	0.7657	0.2778
2002	0.2360	0.5172	0.1985	0.6448	0.2293
2003	0.2549	0.6150	0.1971	0.8275	0.2001
2004	0.2473	0.5993	0.1914	0.8057	0.3497
2005	0.2308	0.5530	0.1815	0.7409	0.3229
2006	0.1828	0.4455	0.1208	0.7307	0.5485
2007	0.1490	0.3800	0.1016	0.5671	0.4521
2008	0.1692	0.7977	0.0148	0.3388	0.2111
2009	0.8512	0.4325	0.9449	0.3142	0.2408
2010	0.3804	0.3965	0.3841	0.2113	0.1624
2011	0.2625	0.0824	0.2705	0.2251	0.4697
2012	0.2914	0.5391	0.2814	0.0780	0.4652
2013	0.3054	0.7242	0.2765	0.0718	0.4614
2014	0.2953	0.5096	0.2661	0.0450	0.4907
Mean	0.2930	0.4998	0.2554	0.4781	0.3429

- The criterion layer evaluation results (table 1) show that the evaluation value of the water resources subsystem, economic subsystem, and ecological subsystem increased with fluctuation. The bearing capacity of each subsystem steadily increased, as did their contributions to the comprehensive bearing capacity. For the water resources subsystem, its main index water supply module rose from 3.30 in 2000 to 5.33 in 2014, and the annual water supply increased from 30,273 million cubic meters in 2000 to 53,799 million cubic meters in 2014 [17]. For the economic subsystem, the water use per 10,000 Yuan industry gross production value decreased from 76.54 cubic meters in 2000 to 6.54 cubic meters in 2014, and

the repeated use rate of industrial water increased from 47% in 2000 to 68.9% in 2014 [18]. For the ecological subsystem, its increasing evaluation value strongly relates to the significant attention that the Xi'an government placed on the protection and management of the ecological environment. Specifically, forest coverage increased from 41.8% in 2000 to 50.4% in 2014, and the urban sewage treatment rate rose from 23.11% in 2000 to 92.71% in 2014 [18]. For the social subsystem, however, its evaluation values show a significant downward trend; it decreased from 0.8056 in 2000 to 0.4781 in 2014. The social subsystem is mainly affected by the total population, population density, rate of urbanization, urban per capita living water consumption, and urban living water consumption. From the changes to these indexes, we found that the urban per capita living water consumption and urban living water consumption increased with the increase in the total population, population density, and rate of urbanization. For example, the total urban living water consumption increased from 10,949 million cubic meters in 2000 to 27,819 million cubic meters in 2014 [18], which put pressure on the social subsystem and reduced its contribution to the water resources bearing capacity.

- The dynamic evolution trend shows that the changing trend of the water resources bearing capacity is similar to those of the economic subsystem and water resources subsystem, indicating that the economic subsystem is an important factor affecting the water resources bearing capacity. This may be because the total demand of water resources increases with the rapid development of economy, which to some extant increases the pressure of the water resources bearing capacity. The total water resource is an important base of the water resources bearing capacity. The average contribution of the water resources subsystem is 4.998, which is the greatest contribution of the four subsystems. However, the uneven time distribution of the water resources leads to a fluctuation in the evaluation value of the water resources subsystem. Therefore, in order to cause the water resources subsystem evaluation value to steadily increase, it is necessary to take the uneven time distribution of water resources into consideration. We can accumulate the water resources of the wet season to make up for the dry season water resources. Although the Xi'an water resources bearing capacity increases over time, the evaluation value is still at a low level of about 0.29. The reasons are as follows: 1) the scarcity of water resources and the low utilization of water resources; 2) the population pressure and residents' insufficient water saving consciousness; and 3) the irrational industrial structure. In Xi'an, the proportion of the second industry and the third industry is high, thereby increasing industrial water and agricultural irrigation water. At present, Xi'an is in an important period of rapid economic and social development, and the gradual improvement of people's living standard has objectively caused pressure on the water resources bearing capacity.

5.2. Transverse evaluation and analysis of the water resources bearing capacity of Xi'an
Through transverse evaluation and analysis, we discovered the regional differences in the water resources bearing capacities of the Xi'an districts. This allows for an exploration of effective ways to improve the bearing capacity of water resources from the perspective of regional coordination. The evaluation results are shown in table 3.

Table 3. The differences in the water resources bearing capacities of the Xi'an districts in 2014.

Region	Comprehensive bearing capacity (A)	Water resources subsystem (B$_1$)	Economic subsystem (B$_2$)	Social subsystem (B$_3$)	Ecological environment subsystem (B$_4$)
Urban areas[a]	0.7432	0.8150	0.7334	0.8908	0.8341
Lantian	0.2499	0.3750	0.1256	0.1721	0.2337
Zhouzhi	0.3377	0.3700	0.1255	0.3373	0.4142
Huxian	0.3388	0.3656	0.0074	0.3565	0.4293
Gaoling	0.2998	0.0268	0.4081	0.2549	0.1900

[a]Urban areas include the Xincheng District, Beilin District, Lianhu District, Baqiao District, Weiyang District, Yanta District, Yanliang District, Lintong District, and Changan District.

- The target layer evaluation results (table 3) show that in 2014 the comprehensive evaluation value of the water resources bearing capacity of urban areas was 0.7432. The water resources bearing capacities of the Xi'an districts from high to low are as follows: Huxian, Zhouzhi, Gaoling, and Lantian. Lantian's evaluation value was the lowest at 0.2499, with both the evaluation values of the economic subsystem and social subsystem below 0.2. The main reason for the high bearing capacity of Huxian is the great contributions of the ecological subsystem and the water resources subsystem. Zhouzhi is second only to Huxian due to the great contribution of the ecological subsystem. Overall, the ecological subsystem and water resources subsystems contribute the most to the improvement of the water resources bearing capacity in Xi'an, whereas the economic subsystem and social subsystem's contributions are lower. At present, in the transition of rapid social and economic development, the increase in the residents' living water consumption objectively causes pressure on the water resources bearing capacity, which reduces the contributions of the economic subsystem and social subsystem. At the same time, it is difficult to make a breakthrough in technology concerning water resources utilization and water saving.

- The criterion layer evaluation results show that the evaluation value of the water resources subsystem in urban areas was 0.8150 in 2014. The evaluation values of the Xi'an districts from high to low are as follows: Lantian, Zhouzhi, Huxian, and Gaoling. Gaoling's evaluation value was the lowest at 0.0268, which is correlated to its low precipitation and low water supply comprehensive production capacity. For the economic subsystem, the evaluation values from high to low are as follows: urban areas, Gaoling, Lantian, Zhouzhi, and Huxian. The highest value was that of the urban areas at 0.7334, and the lowest value was that of Huxian at 0.0074. In Huxian, the water demand for production and operation increased with the development of economy; however, in this region, water-use efficiency is very low, causing much pressure on its water resources bearing capacity. For the social subsystem, the evaluation values from high to low are as follows: urban areas, Huxian, Zhouzhi, Gaoling, and Lantian. The highest value was that of the urban areas at 0.8908, and the lowest value was that of Lantian at 0.1721, which is strongly related to its expanding population and increasing per

capita daily water consumption. In regards to the ecological subsystem, the evaluation values from high to low are urban areas, Huxian, Zhouzhi, Lantian, and Gaoling. Gaoling needs further attention and support with the lowest value of 0.19.

6. Recommendations

Based on the above results and discussion, several important recommendations are made below:

For the water resources subsystem, we need to rationally develop, utilize, and protect water resources in order to improve the water resources bearing capacity, and the government should increase its investment in water conservancy construction in order to increase the overall supply of water resources. First, new water resources should be found and explored. In the medium to long term, in addition to the Heihe Water Diversion Project and Lijiahe Reservoir Water Diversion project, the Xi'an government should promote the development of the Northeastern Suburbs Water Resources, Jinghe Dongzhuang Reservoir Water Supply, and Two Rivers Water Transfer project. Second, the protection and governance of water resources should be strengthened. The government needs to protect drinking water sources, promote water-saving technology, and make full use of surface water resources. Meanwhile, there should also be efforts to scientifically and rationally mine water resources and actively collect rainwater resources. Third, the efficiency of urban sewage reuse should be improved, and sewage should be transformed into resources. By improving the urban sewage treatment system by promoting mid-water reuse technology, we are able to use water resources more effectively and comprehensively. The treatment of sewage can lead to an achievement of water quality standards, and it can be used in the fields of urban landscape, agricultural irrigation, industrial cooling water, and public facilities (such as flushing).

For the economic subsystem, first, the provincial government should adjust the industrial structure in order to optimize the industrial layout, giving priority to the development of low water consumption projects and moderately-controlled high water consumption projects. Furthermore, the Xi'an government needs to formulate the industrial layout properly according to the water resources in different regions and avoid developing high water consumption industries in water scarcity areas. In addition, the government should eliminate industries with high water consumption, heavy pollution, and out-of-date technology. Second, we should improve water use efficiency and water saving efficiency in industry. As one of the pillar industries in our economy, industry water consumption is second only to agriculture. In Xi'an, industrial water consumption is increasing with the acceleration of industrialization. Therefore, we should accelerate innovations in production technology and equipment modification in industry to improve the utilization efficiency of industrial water resources and perfect the industrial wastewater treatment facilities to improve the water reuse rate and reduce water waster. At the same time, the government needs to strengthen its supervision of the production process and focus on promoting water saving technology in five high water consumption industries: thermal power, textile, petrochemical, paper, and steel.

For the subsystem, first, residents' water saving consciousness should be raised through information and education. The pressure from urban water resources was primarily linked to population because water demand inevitably increases with an expanding population. At present, the population density of Xi'an has increased from 696 people/square kilometers in 2000 to 854 people/square kilometers in 2014, and the total population has increased from 688 million in 2000 to

815 million in 2014, thereby intensifying water supply pressure. Therefore, the government should reasonably control the population growth so as to alleviate the social pressure of water supply and demand. Meanwhile, residents' traditional water habits need to be changed through information and education. For example, the government can promote water-saving appliances to the public in order to improve the utilization efficiency of water resources and conserve water resources. In addition, in order to achieve the optimal allocation or quasi-optimal allocation of water resources, the government should establish standard water prices according to the scarcity degree of water resources, thus improving the pricing mechanisms of water resources.

For the ecological subsystem, it is important to strengthen the protection and governance of the ecological environment in Xi'an. First, the forest cover rate in Xi'an needs to be increased. Although the forest cover rate has increased to around 50% in the past 10 years, we still need to take measures to increase the forestation area in the future. Meanwhile, the government should strengthen the protection and management of the forest ecosystem, giving full attention to the water storage and water production function of forest resources, which is an effective way to improve the water resources bearing capacity. Second, measures should be taken to strengthen the prevention of water pollution. Although the quality of water resources in Xi'an has improved significantly recently, urban sewage discharge still increases every year, of which second industrial wastewater and domestic sewage discharge occupies a great proportion. Therefore, the government should take relevant measures to strengthen the prevention and governance of wastewater. In terms of prevention, the government should strengthen the supervision of wastewater discharge and prohibit the direct discharge of untreated wastewater. In terms of governance, the government should focus on the protection of the water resources ecological environment and increase its investment in water pollution governance in order to improve the sewage treatment capacity.

7. Conclusions

In this paper, by constructing an evaluation index system including the economy, society, water resources, and ecological environment, we empirically evaluated the water resources bearing capacity of Xi'an in 2000-2014. The conclusions are as follow: 1) The water resources bearing capacity of Xi'an reached a maximum in 2007 and a minimum in 2009, which strongly relates to the fact that Xi'an increased its investment in water conservancy construction and developed a series of policies and measures to protect the environment since the 20th century. 2) The water resources bearing capacity varies across districts, and the evaluation value of the water resources bearing capacities from high to low areas as follows: urban areas, Huxian, Zhouzhi, Gaoling, and Lantian. Lantian requires further attention because it had the lowest evaluation. 3) In general, the water resources bearing capacity increases over time. The contributions of the subsystems from high to low are the water resources subsystem, social subsystem, ecological subsystem, and economic subsystem. 4) The water resources bearing capacity of Xi'an is still at a low level. The possible reasons for this are as follows: the scarcity of water resources, population pressure, insufficient water saving consciousness of residents, increasing per capita living water consumption, and irrational industrial structure.

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