Analysis of the Break-even and Load Index of Water Resources in Beijing

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ABSTRACT

The change of water resources quantity and water resources supply are elaborated in this paper to analyze water resources in Beijing. On this basis, the profit-loss amount and the profit-loss rate of water resources in Beijing are calculated by using break-even analysis. The water resource load index method is also employed to calculate the population and economic scale that can be supported by water resources in Beijing, and then reveal the relationship between water resources, population and economic development in Beijing. The results show that during the period from the 10th five-year plan to the 13th five-year plan, the total amount of water resources and the water resources per capita in Beijing have increased on the whole, but they are far below the internationally recognized warning line of extreme water shortage. The water resources in Beijing are in a state of "break-even", among which the surface water resources are in an alternating state of "break-even - surplus - break-even", while the groundwater resources are in a state of "break-even" to "surplus". The load index of water resources in Beijing continues to improve, and the population-economic scale of load per unit of water resources has reached medium level.

Keywords: Beijing, Water resources, Supply, Break-even, Load index.

1. INTRODUCTION

Water resource is a strategic resource for sustainable economic and social development of Beijing, which provides a guarantee for economic and industrial development, residents' life and environmental protection. Accelerating the transformation and upgrading of industrial structure in the process of modernization in Beijing is conducive to improving the efficiency of intensive utilization of water resources. However, the economic and social development of Beijing is still facing the problems of intensified contradiction between supply and demand of water resources and increasing pressure of supply and demand of water resources. Therefore, it is urgent to conduct in-depth research on the water resources of surface water and groundwater, the population supported by water resources and the economic scale in Beijing, so as to provide decision-making support for the optimal allocation of water resources in Beijing. At present, the research on the evaluation of water resources utilization in Beijing mainly focuses on three aspects: the risk assessment of water resources supply and demand in Beijing [1-5], the evaluation of water resources carrying capacity in Beijing [6-7], and the coordination evaluation of water resources and economic development in Beijing [8-13]. However, few scholars have analyzed the break-even of water resources in Beijing during different planning periods and evaluated the load capacity of water resources on population and economic development in Beijing. Therefore, the break-even and water resource load index are used to analyze the water resource break-even and water resource load index of Beijing in different planning periods.

2. CHANGES OF WATER RESOURCES IN BEIJING

2.1 Change of Water Resource Quantity

With a large population and a booming economy, Beijing faces the plight of a relative shortage of water resources, both in total and available, which leads to low per capita water resources. Therefore, Beijing has become the province with the lowest per capita water resources in China, and it is a resource-deficient megacity. From 2000 to 2019, the fluctuation pattern of the total water resources in Beijing has changed significantly, from 1.686 billion cubic meters in 2000 to 3.95 billion cubic meters in 2012, and then decreased to 2.46 billion cubic meters in 2019. From the 10th five-year plan period to the 13th five-year plan period, the change of water resources in Beijing is relatively significant, as shown in "Table 1".

Table 1. Changes of water resources in Beijing during the 10th five-year plan to the 13th five-year plan

Planning period	Total water resources Average value/100 million cubic meters	Surface water resources Average value/100 million cubic meters	Groundwater resources Average value/100 million cubic meters	Water resources per capita Average value/cubic meter
10th five-year plan period	19.65	6.96	16.04	134.37
11th five-year plan period	25.00	8.21	19.69	141.64
12th five-year plan period	27.64	10.47	20.59	131.76
13th five-year plan Period	31.25	12.23	24.55	144.46

a   Note: The "13th five-year plan" period mainly refers to statistical data from 2016 to 2019, the same below.

According to "Table 1", the mean amount of water resources in Beijing increased from the 10th five-year plan to the 13th five-year plan, with an increase rate of 59%. However, during the 13th five-year plan period, the average amount of water resources in Beijing is only 3.125 billion cubic meters. Among them, the average growth rate of surface water resources was faster than that of groundwater resources, with an increase rate of 76% and 53% respectively. During the 10th five-year plan period, the average amount of groundwater resources was 2.30 times that of surface water resources, and decreased to 2.01 times in the 13th five-year plan period. As for the per capita water resources in Beijing, from the 10th five-year plan period to the 13th five-year plan period, it showed an overall growth trend, from 134.37 cubic meters to 144.46 cubic meters, but it is far below the internationally recognized warning line of 500 cubic meters for extreme water shortage. By 2019, per capita water resources in Beijing will drop to 114.23 cubic meters.

2.2 Changes in Water Supply

The water supply of Beijing mainly includes surface water supply, groundwater supply, and other water supply (including water from south to north, reclaimed water, seawater desalination, etc.). From the 10th five-year plan period to the 13th five-year plan period, the average water supply in Beijing increased continuously, from 3.552 billion cubic meters to 3.92 billion cubic meters. The change of water resources supply in Beijing during the 10th five-year plan to the 13th five-year plan is shown in "Table 2".

Table 2. Changes of water resources supply in Beijing during the 10th five-year plan to the 13th five-year plan

Planning period	Surface water supply	Proportion of surface water supply	Groundwater supply	proportion of groundwater supply	Other water supply	proportion of Other water supply
	Average value/100 million cubic meters	Average value/%	Average value/100 million cubic meters	Average value/%	Average value/100 million cubic meters	Average value/%
10th five-year plan period	8.62	24.13	25.72	72.47	1.18	3.40
11th five-year plan period	6.45	18.44	22.89	65.50	5.63	16.06
12th five-year plan period	8.83	23.95	19.82	53.96	8.14	22.09
13th five-year plan period	12.77	31.98	16.37	41.16	10.71	26.86

"Table 2" shows that from the 10th five-year plan period to the 13th five-year plan period, the total surface water supply in Beijing increased slowly, with an increase rate of 48%. The average proportion of surface water supply in Beijing has increased by 7.85%. In addition, the total amount of groundwater supply in Beijing decreased by 36%. The average proportion of groundwater supply in Beijing has dropped by 31.31 percentage points. Other water supplies in Beijing increased rapidly overall, with an average increase of 9.08 times. The average proportion of other water supplies in Beijing has increased by 23.46 percentage points. The comparison of surface water supply, groundwater supply and other water supply shows that the average amount of groundwater supply in Beijing is the largest during the 10th five-year plan period to the 13th five-year plan period, but the multiple between the average amount of groundwater supply and the average amount of surface water supply decreases slowly, from 2.98 times to 1.28 times. At the same time, the multiples of the mean water supply of groundwater and other water supplies decreased rapidly, from 21.80 to 1.53 times.

3. ANALYSIS OF WATER RESOURCES BREAK-EVEN IN BEIJING

There is a serious imbalance between the supply and demand of water resources in Beijing and the total amount of water resources is not enough to meet the water supply. The contradiction between the shortage of water resources and the rapid development of economy and society in Beijing leads to the overdependence of groundwater resources in Beijing. In view of the change of the total amount of water resources and water supply in Beijing, the break-even analysis method was adopted to analyze

the break-even of water resources in Beijing during the 10th five-year plan period and the 13th five-year plan period, as shown in "Table 3".

Table 3. Analysis on the break-even of Water Resources in Beijing during the 10th five-year plan Period and the Thirteenth Five-year plan Period

Planning period	Total break-even of water resources	Total break-even ratio of water resources	Total break-even of surface water resources	Total break-even ratio of surface water resources	Total break-even of groundwater resources	Total break-even ratio of groundwater resources
	Average value/100 million cubic meters	Average value/%	Average value/100 million cubic meters	Average value/%	Average value/100 million cubic meters	Average value/%
10th five-year plan period	-15.87	-83.72	-1.66	-29.59	-9.68	-61.46
11th five-year plan period	-9.97	-43.82	1.75	15.58	-3.20	-18.01
12th five-year plan period	-9.14	-39.76	1.64	4.75	0.77	1.29
13th five-year plan period	-8.58	-30.83	-0.55	-11.39	8.18	32.22

a   Note: break-even of water resources = total water resources - water supply; break-even ratio of water resources = break-even of water resources/total water resources.

3.1 Changes in Break-even of Water Resources

"Table 3" shows that during the 10th five-year plan period and the 13th five-year plan period, the water resources of Beijing presents a "break-even" state. However, the mean absolute value of total water resources break-even in Beijing has been shrinking continuously from 1.587 billion cubic meters to 858 million cubic meters, with a decrease of 45.94%. The surface water resources are in an alternating state of "break-even - surplus - break-even". During the 10th five-year plan period, the absolute value of the average break-even of Beijing's surface water resources was 166 million cubic meters. During the 11th five-year plan period and the 12th five-year plan period, Beijing's surface water resources changed from break-even to surplus, but the average surplus of Beijing's surface water resources decreased from 175 million cubic meters to 164 million cubic meters. During the 13th five-year plan period, Beijing's surface water resources turned to break-even again, and the absolute value of the average break-even of surface water resources was 55 million cubic meters. The groundwater resources in Beijing have changed from "break-even" to "surplus" state. During the 10th five-year plan period and the 11th five-year plan period, the mean absolute value of break-even of groundwater resources in Beijing decreased from 968 million cubic meters to 320 million cubic meters. From the 12th five-year plan period to the 13th five-year plan period, the groundwater resources in Beijing have changed from break-even to surplus. The average surplus of groundwater resources has continued to expand from 77 million cubic meters to 818 million cubic meters, an increase of 10.6 times.

3.2 Change of Break-even Ratio of Water Resources

"Table 3" shows that from the 10th five-year plan period to the 13th five-year plan period, the total break-even ratio of water resources in Beijing continued to shrink, with the absolute value of its mean value dropping from 83.72% to 30.83%, a decline of 52.89 percentage points. The break-even ratio of surface water resources in Beijing is generally reduced. During the 10th five-year plan period, the absolute value of the mean break-even ratio of surface water resources was 29.59%. From the 12th five-year plan period to the 12th five-year plan period, the average surplus ratio of surface water resources dropped from 15.58 percent to 4.75 percent, a decrease of 10.83 percentage points. During the 13th five-year plan period, the average break-even ratio of surface water resources is 11.39%. From the 10th five-year plan period to the 13th five-year plan period, the mean absolute value of the break-even ratio of surface water resources decreased by 18.2 percentage points. The break-even ratio of groundwater resources in Beijing is decreasing rapidly and entering the period of surplus of groundwater resources. From the 10th five-year plan period to the Eleventh Five-year plan period, the mean absolute value of break-even ratio of groundwater resources decreased from 61.46% to 18.01%, a decrease of 43.45 percentage points. From the 12th five-year plan period to the 13th five-year plan period, the average surplus rate of groundwater resources increased from 1.29% to 32.22%.

4. WATER RESOURCE LOAD INDEX OF BEIJING

4.1 Calculation Method of Water Resource Load Index

$$C(t) = K(t)\sqrt{P(t) \cdot G(t)} \Big/ W(t) \tag{1}$$

In Formula (1), $C(t)$ is the load index of water resources in Beijing in the period t ; $P(t)$ is the population size (ten thousand people) of Beijing in the period t ; $G(t)$ is the gross domestic product (100 million yuan) of Beijing in the period t ; $W(t)$ represents the total water resources (100 million cubic meters) of Beijing in the period t ; $K(t)$ is the coefficient related to precipitation in Beijing in the period of t, which can be expressed by the formula below.

The water resource load index of Beijing is mainly expressed by the population and economic scale that can be supported by the water resources of Beijing, which reflects the relationship between the water resources of Beijing and the population and economic development. The formula can be expressed as

$$K(t) = \begin{cases} 1.0 & R(t) \le 200 \\ 1.0 - 0.1(R(t) - 200)/200 & 200 < R(t) \le 400 \\ 0.9 - 0.2(R(t) - 400)/400 & 400 < R(t) \le 800 \\ 0.7 - 0.2(R(t) - 800)/800 & 800 < R(t) \le 1600 \\ 0.5 & R(t) > 1600 \end{cases} \tag{2}$$

In Formula (2), $R(t)$ is the precipitation in Beijing (mm) during the t period.

The water resource load index of Beijing reflects the population-economic scale of the water resource load per unit of Beijing. The lower the index is, the lower the degree of population-economic scale of Beijing's water resource load is, and there is still some room for improvement of Beijing's water resource load index. The classification of water resource load index is shown in "Table 4".

4.2 Calculation of Water Resource Load Index

According to Formula (1) and (2), the change of water resource load index of Beijing in different periods can be calculated, as shown in "Table 5".

Table 4. Classification of water resource load index

Rank	water resource load index	population-economic scale of the water resource load per unit
I	>10	very high
II	5-10	high
III	2-5	medium
IV	1-2	relatively low
V	<1	low

Table 5. Water resource load index of Beijing in different periods

period	water resource load index	period	water resource load index	period	water resource load index
2000	1.09	2011	1.76	10th five-year plan period	1.21
2001	1.03	2012	1.15	12th five-year plan period	1.54
2002	1.37	2013	2.22	12th five-year plan period	2.04

2003	1.28	2014	2.94	13th five-year plan Period	2.17
2004	1.17	2015	2.13		
2005	1.22	2016	1.64		
2006	1.43	2017	2.10		
2007	1.45	2018	1.83		
2008	1.01	2019	3.01		
2009	1.91	2000-2019	1.69		
2010	1.91				

According to "Table 5", the fluctuation of the water resource load index in Beijing has increased from 2000 to 2019. In 2008, the water resource load index was the lowest, which was only 1.01. In 2013, the average water resource load index exceeded 2.0. In 2019, the average water resource load index exceeded 3.0. During the period from the 10th five-year plan to the 13th five-year plan, the average value of the water resource load index in Beijing continued to increase, with an increase rate of 79.34%. According to the classification of water resource load index in "Table 4", the degree of population-economic scale of the water resource load per unit in Beijing has reached medium level.

5. CONCLUSION

During the period from the 10th five-year plan to the 13th five-year plan, the total amount of water resources in Beijing increased. Although the amount of groundwater resources exceeded that of surface water resources, the latter increased faster than the former. Per capita water resources have increased on the whole, far below the internationally recognized warning line of extreme water shortage. The water supply of surface water in Beijing increased slowly, the water supply of underground water decreased, and other water supply increased rapidly. The multiples of groundwater supply and surface water supply decreased slowly, so did the multiples of groundwater supply and other water supply. The water resources in Beijing are in a state of "break-even", among which the surface water resources are in an alternating state of "break-even - surplus - break-even", while the groundwater resources are in a state of "break-even" to "surplus". The total break-even ratio of water resources, surface water resources and groundwater resources in Beijing are shrinking rapidly, ushering in the surplus period of groundwater resources. The average value of water resource load index in Beijing continues to improve, and the population-economic scale of load per unit has reached medium level.

AUTHORS' CONTRIBUTIONS

Dan Wu is responsible for experimental design and writing the manuscript, Yanlai Jin, Yongkuan Wang, Hao Shen are responsible for analysed data and writing the manuscript.

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