A comprehensive analysis on water resources carrying capacity in Tongliao based on ecological footprint method

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Abstract. How to judge the sustainable utilization and carrying capacity of water resources is an important issue for scholars and governments. Based on the theory of ecological footprint, this paper uses the ecological footprint method to calculate the water resources carrying capacity of Tongliao City, and carries out a comprehensive evaluation and analysis on the water resources from both societal and economic perspectives. The result shows that the water resources in the city from 2011 to 2014 is in a state of ecological deficit and overloaded, but from 2015 to 2017 turns to the ecological surplus state.The study would provide local authorities solid data for formulating appropriate regulations for water resource protection and development.

1. Introduction

Water resources carrying capacity is a concept based on the study of water resources, water environment and sustainable development. Fangguohua calculated the ecological footprint of fresh water resources and the ecological carrying capacity of fresh water resources, obtained the relationship between ecological footprint and ecological carrying capacity[1].Liu Xiangyun calculated the ecological footprint, ecological surplus (or ecological deficit) of the water resources in Karst region by using the ecological footprint method.The ecological footprint of water resources of 10,000 yuan GDP is calculated, the carrying capacity of water resources in this area is comprehensively analyzed according to these data[2]. According to Ma Lixin and other's study, the water resources carrying capacity of Tongliao city is evaluated and analyzed from multi-level and with multi-index.It was found that the carrying capacity of water resources in Tongliao was at a low level[3]. Through consulting the data, we know that there are many studies on the water resources carrying capacity of each region by the ecological footprint method, but there is no study on the sustainable utilization of water resources carrying capacity of Tongliao by the ecological footprint method. Based on previous studies, the ecological footprint method can estimate the occupancy of human assets to natural assets and the comprehensive carrying capacity of the research area. It can also estimate the ability of human to develop and utilize water resources to build "nature-society-economy" complex systems to measure regional water resources. Using the ecological footprint method,This paper calculates the ecological surplus of water resources and the ecological footprint of water resources of one million yuan GDP in Tongliao City, analyzes the carrying capacity of water resources in Tongliao City, and studies the relationship between the sustainable development of water resources and the social and economic development of Tongliao City from the economic point of view.

2. The general situation of the research area

According to the government data, the average total surface water of water resources in Tongliao is about 839 million stere, the total amount of groundwater is about 3 billion 530 million 830 thousand stere, a total of 4 billion 369 million 830 thousand stere. The total amount of calculation for subtracting surface water and groundwater from each other is about 582 million 950 thousand stere. Finally, the annual average water resources in Tongliao are about 3 billion 786 million 880 thousand stere. The average amount of groundwater is about 2 billion 796 million 150 thousand m^3, the surface water can be used about 437 million 290 thousand stere, but the amount of surface water available in Tongliao is the amount of repeated calculation, so the total amount of water resources in Tongliao can be used in the total amount of about 2 billion 796 million 150 thousand stere[4].The development and utilization of water resources can be seen in Table 1.

Table 1. The development and utilization of water resources in Tongliao

	Ground water			**Surface water**			**Gross amount of water resources**		
Subregion	Water resources quantity [10,000 m^3]	Water supply [10,000m^3]	Deveopment rate [%]	Water resources quantity [10,000 m^3]	Water supply [10,000 m^3]	Development rate [%]	Gross amount of water resources [10,000m^3]	Aggre-gat supply [10,000 m^3]	Utilization ratio of water resources development [%]
whole	353081	274100	77.6	88018	6208	7	441099	280308	63.5

Through the above data, it is known that the percentage of water consumption in the primary industry of Tongliao is the highest in the area, so the water consumption fluctuation in the industry is the biggest demand for the development of the area, but the GDP generated by the primary industry is only 14.2%, so the use of water resources is not suitable. Therefore, it is necessary to adjust the planting structure of the primary industry and adopt some corresponding water-saving measures to solve the problems of low efficiency of water usage and improper water utilization structure in Tongliao. According to the investigation and research, the technical level of the water resources development and utilization of Tongliao is relatively low, the social and economic development is also at the middle level, the water resources are scarce and the way of utilization is also unscientific.Therefore, the sustainable development of water resources in Tongliao is very important. Because the bearing capacity of water resources is closely related to the technical level of the development and utilization of water resources in this area, the current utilization of water resources is in an unsuitable state. Therefore, the carrying capacity of water resource should be evaluated and analyzed.

3. Data sources and research methods

3.1. Data sources

The data mainly came from the the Inner Mongolia Autonomous Region Water Conservancy Bureau official network from 2011 to 2017, the the Inner Mongolia Autonomous Region water resources bulletin, the Tongliao Municipal Statistical Bulletin, the Tongliao Statistics Bureau from 2011 to 2016, the Research Report on the water resources carrying capacity of the "13th Five-Year" period of Tongliao,the regional economy in 2016 of Tongliao, and social development statistics bulletin and Inner Mongolia water conservancy journal.

3.2. Research methods

3.2.1 Calculation of ecological footprint

- Aggregate the ecologically productive land occupied by per capita production and consumption projects.
- TEquivalent factor (alpha): the equivalent factor is an equivalent coefficient that changes the productive land of the different species into the birth. State productivity, and its formula is:

$$\alpha = P_i/P \quad (1)$$

α is the equivalent factor of some kind of ecological production. The P_i means the average ecological productivity of this kind of ecological and productive land. P refers to the average ecological productivity of all types of productive land in the world.

- The equivalent amount of land occupied by all kinds of ecological production in Tongliao is calculated.
- The formula for calculating Eco-productive land area per person occupied by various consumption items:

$$A_i = C_i/P_i \quad (2)$$

P_i is the annual average productivity of the corresponding Eco-productive land production item i [kg / hm^2)], and C_i is the per capita annual consumption value of item i.

- The total ecological footprint of all kinds of people (ef):

$$ef = \sum \alpha A_i \quad (3)$$

- The ecological footprint (EF) of the total population in this area is calculated as follows:

$$EF=N^* (ef) \quad (4)$$

The calculation of ecological footprint is based on the general model of ecological footprint theory. The formula of ecological footprint is:

$$EF_w = N * ef_w = N * \sum_{i=1}^{n} A_w * W_i/P_w \quad [5] \quad (5)$$

EF_w is the ecological footprint of water resources in Tongliao [hm^2]; EF_W is the per capita ecological footprint of Tongliao [hm^2 / person]; A_w is the balance factor of water resources; W_i is the consumption of all kinds of water. The quantity of resources [m^3]; P_w is the raw of water resources in Tongliao. The production capacity [m^3 / hm^2].

3.2.2 Calculating the carrying capacity of water resources by the ecological footprint method.
According to the ecological footprint method, the water resources capacity of Tongliao is calculated as follows:

$$EC_w = N * eC_w = 0.4 * N * a_w * f_w * Q_w/P_w \quad [5] \quad (6)$$

EC_w is the ecological capacity of Tongliao water resources (hm^2), N is the population of Tongliao region, eC_w is the ecological capacity of the per capita water resources of Tongliao city (hm^2/ people), a_w is equilibrium factor of water resources, fw is water resources yield factor, Q_w is the total amount of water resources in Tongliao region (m^3) and Pw is the average production capacity of water resources (m^3/hm^2).

3.2.3. Calculation of ecological surplus (or deficit)
The formula for calculating the ecological surplus (or deficit) of water resources is:

$$Bg = EC_w - EF_w \quad (7)$$

Bg refers to the ecological surplus (or deficit) of water resources in the region, EC_w is the bearing capacity of water resources in the region [hm^2], and EFw is the ecological footprint of water resources in this area [hm^2]. The ecological footprint of water resources is a measure of the ecological sustainable utilization of water resources in this area, which is mainly based on the ecological deficit of water resources or the ecological surplus of water resources. If $Bg < 0$, the water resources in this area are ecological deficit, which indicates that the water supply in this area is insufficient and can not meet the needs of the development of this region. The water resources in this area are ecological surplus when $Bg > 0$, which shows that the total water resources in this area can not only meet the needs of the ecological environment, but also the water resources in this area are ecological surplus. And it can also maintain the need of economic development in this area, when the water resources in

the region have a good sustainable development; Bg=0 indicates that the water resources in the region have an ecological balance.

4. Comprehensive evaluation of water resources carrying capacity in Tongliao

4.1. Accounting of water resources ecological footprint and water resources carrying capacity in Tongliao

The total amount of water resources in the area is obtained by reducing the amount of groundwater and surface water in a region, so that the amount of water resources in Tongliao is the total amount of surface water in this area. According to the data of the official network of the the Inner Mongolia Autonomous Region Water Conservancy Bureau, the the Inner Mongolia Autonomous Region water resources bulletin, the statistical bulletin of Tongliao, and the Statistics Bureau of Tongliao, the water supply and water consumption of Tongliao are summarized as follows:

Table 2. Water resources in Tongliao city [100million cubic meters]

Time	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Ground water	34.7	33.6	34.6	35.4	35.9	36.1	35.7
Surface water	7.9	8.2	8.7	9.1	8.6	8.2	8.8
Total water resources	34.7	33.6	34.6	35.4	35.9	36.1	35.7

Table3. Water consumption accounting in Tongliao city[100million cubic meters]

Time	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Time**
Water for life	**village**	0.36	0.4	0.37	0.31	0.34	0.31	0.35
	town	0.51	0.56	0.5	0.47	0.51	0.49	0.47
Production water supply	**agriculture**	23.6	23.56	23.12	23.51	22.7	23.14	22.87
	industry	2.22	2.4	2.32	1.98	2.08	2.17	2.16
Ecological water use	**Ecological water use**	0.34	0.33	0.3	0.34	0.37	0.34	0.4

(1) Yield factor: because the same species has ecoecological and productive land, the productive force is inconsistent in different places, so it is not the same kind of living soil in a place. The actual area of the ground can not be directly compared. Generally speaking, yield factor refers to a unified parameter that transforms the same ecologically productive land of different regions and countries into a comparable area. According to the formula of yield factor of water resources:

$$F_w = P/P_o \qquad (8)$$

F_w is the yield factor of water resources, P is the total amount of water per unit area [m^3/hm^2] and P_o is the total unit area of water perunit [m^3/hm^2] in the world.

According to the data of the the Inner Mongolia Autonomous Region water resources bulletin, the water output per unit area of Tongliao is 7409 m^3/hm^2. According to the world resources, the output per unit area of the world is 3140 m^3/hm^2 per year. The data is brought into the formula, the water resources yield factor of Tongliao City is 2.36.

(2) Equilibrium factor: there is a very big difference in the production capacity of different land use species per unit area, which can be compared and have a consistent ecological birth area after each ecological birth area multiplied by a fixed equilibrium factor, and usually we define the balance factor of water resources as a factor. Unit 1 is calculated.

(3) According to the Tongliao Water Conservancy Bureau, we can know that the utilization rate of water resources in Tongliao city in 2011-2017 is respectively56.4%,58.7%,56.1%,61.8%,63.5%,66.1% ,67.4%.

(4) Calculation results of ecological footprint and carrying capacity of water resources per capita in Tongliao city from 2011-2017 year.The results of the calculation are shown in table 4-10 in table below:

[demand area, equilibrium area, ecological footprint and carrying capacity are all hm2/ people].

Table4

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0036	1	0.0036	Ground water	0.3474	2.36	1	0.8199
	town	0.0051	1	0.0051					
Production	Agriculture	0.236	1	0.236	Surface water	0.0792	2.36	1	0.1869
Watersupply	Industy	0.0222	1	0.0222					
Ecological water use		0.0034	1	0.0034	Total	0.3474	2.36	1	0.8199
Per capita ecological footprint of water resources:0.2703					Per capita water resources carrying capacity :0.2682 Water resource utilization capacity percapita:0.1513				

Table5

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.004	1	0.004	Ground water	0.3363	2.36	1	0.7937
	town	0.0056	1	0.0056					
Production	Agriculture	0.2356	1	0.2356	Surface water	0.0817	2.36	1	0.1928
Watersupply	Industy	0.024	1	0.024					
Ecological water use		0.0033	1	0.0033	Total	0.3363	2.36	1	0.7937
Per capita ecological footprint of water resources:0.2725					Per capita water resources carrying capacity:0.2546 Water resource utilization capacity percapita:0.1495				

Table6

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0037	1	0.0037	Ground water	0.3459	2.36	1	0.8163
	town	0.005	1	0.005					
Production	Agriculture	0.2312	1	0.2312	Surface water	0.087	2.36	1	0.2053
Watersupply	Industy	0.0232	1	0.0232					
Ecological water use		0.003	1	0.003	Total	0.3459	2.36	1	0.8163
Per capita ecological footprint of water resources:0.2661					Per capita water resources carrying capacity:0.2589 Water resource utilization capacity percapita:0.1453				

Table7

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0031	1	0.0031	Ground water	0.3541	2.36	1	0.8357
	Town	0.0047	1	0.0047					
Production	Agriculture	0.2351	1	0.2351	Surface water	0.091	2.36	1	0.2148
Watersupply	Industry	0.0198	1	0.1984					
Ecological water use		0.0034	1	0.0034	Total	0.3541	2.36	1	0.8357
Per capita ecological footprint of water resource:0.2661					Per capita water resources carrying capacity:0.2631 Water resource utilization capacity percapita:0.1626				

Table8

Demand					Supply				
Type		Demand area	Balance factor	Balanc e area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0034	1	0.0034	Ground water	0.3586	2.36	1	0.8463
	Town	0.0051	1	0.0051					
Production	Agriculture	0.227	1	0.227	Surface water	0.0861	2.36	1	0.2032
Watersupply	Industry	0.0208	1	0.0208					
Ecological water use		0.0037	1	0.0034	Total	0.3586	2.36	1	0.8463
Per capita ecological footprint of water resource:0.2660					Per capita water resources carrying capacity:0.2725 Water resource utilization capacity percapita:0.1730				

Table9

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0031	1	0.0031	Ground water	0.3612	2.36	1	0.8524
	Town	0.0049	1	0.0049					
Production	Agriculture	0.2314	1	0.2314	Surface water	0.0816	2.36	1	0.1926
Watersupply	Industry	0.0217	1	0.0217					
Ecological water use		0.0034	1	0.0034	Total	0.3612	2.36	1	0.8524
Per capita ecological footprint of water resources:0.2645					Per capita water resources carrying capacity:0.2796 Water resource utilization capacity per capita:0.1848				

Table10

Demand					Supply				
Type		Demand area	Balance factor	Balance area	Type	Demand area	Yield factor	Balance factor	Balance area
Water for life	Village	0.0034	1	0.0034	Ground water	0.357	2.36	1	0.8425
	Town	0.0047	1	0.0047					
Production Water supply	Agriculture	0.2287	1	0.2287	Surface water	0.0879	2.36	1	0.2074
	Industry	0.0216	1	0.0216					
Ecological water use		0.004	1	0.0041	Total	0.357	2.36	1	0.8425
Per capita ecological footprint of water resources:0.2624					Per capita water resources carrying capacity:0.2691 Water resource utilization capacity per capita:0.1814				

4.2. Accounting for ecological surplus (or ecological deficit) of water resources in Tongliao

Based on the calculation of the ecological footprint and carrying capacity of the preceding water resources, the following is shown in Figure 1:

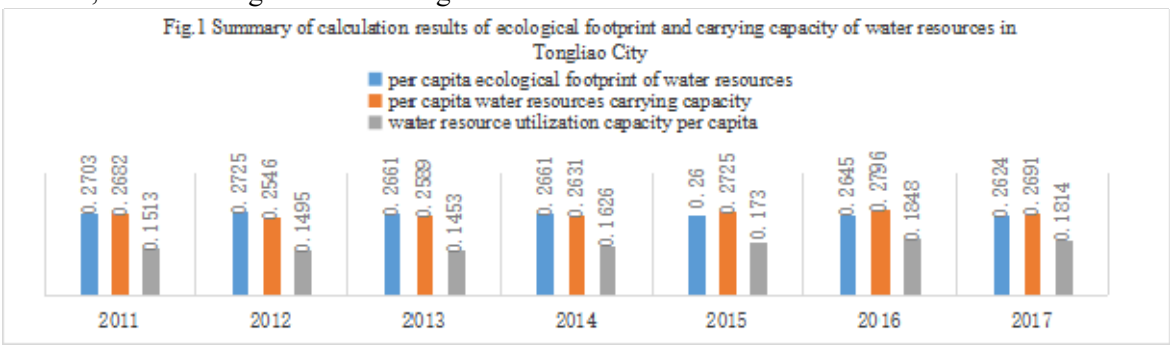


Figure 1 clearly shows that the percapita carrying capacity of water resources in the area from 2011 to 2014 is smaller than the ecological footprint of per capita water resources, and it can be known that Bg < 0, so the water resources of the area from 2011 to 2014 are in a kind of ecological red.The state of the word is overloaded.Tongliao's per capita carrying capacity of water resources is larger than that of per capita ecological footprint in 2015,that Bg > 0, so the water resources in Tongliao resulted in the ecological surplus from 2015 to 2017.

According to the "Assessment measures for implementing the strictest water Resources Management system in Tongliao City" issued by the General Office of the people's Government of Tongliao City on July 16,2015, and the "Action Plan for the Construction of a functional area of 8 million mu of water-saving, High yield and High efficiency Grain in Tongliao City",etc. Some institutional developments and the implementation of some measures include the limit of total water consumption and the control of water use efficiency in Tongliao area, the regulation of water function area, and the regulation of water resources exploitation. During the period of correction, it is necessary to stop the new intake of water from some substandard projects and more rigorous examination and approval of some sewage outlets into the river. Secondly, it is necessary to stop the environmental assessment and approval of major water pollutants and some new construction projects in the region. For some projects which can not meet the requirements after rectification, the relevant personnel in the project area should be held accountable according to law. Due to the implementation of these plans, the utilization efficiency of water resources in the city has been greatly improved, so the water resources began to change the state of ecological surplus after 2015.

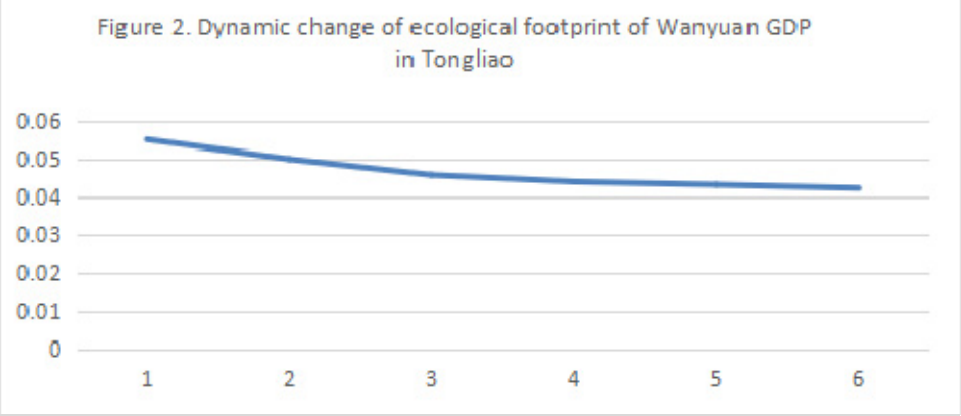
4.3. the ecological footprint of the million yuan GDP water resources in Tongliao

Source ecological footprint refers to the ecological footprint of water resources that can produce every ten thousand yuan of GDP per unit of production in a certain region.It refers to reflect the water resources benefit of this area under certain social development level. Using the link between efficiency and socio-economic growth, the ratio between the ecological footprint of the region's water resources and the region's gross domestic product (GDP), that is, EFGDP = EFw/ GDP.When a region of GDP water resources is growing more and more. The efficiency of water resources in this area is getting

lower and lower, and vice verse. The index can roughly show how the social and economic growth of the region is.

$$\text{Million yuan GDP water resources Source ecological footprint} = (N * ef_w) / GDP \quad [6] \qquad (9)$$

Through the statistical yearbook of Tongliao, it can be found that the GDP of Tongliao city is 164.7 billion yuan, 170 billion yuan, 181.2 billion yuan, 188.9 billion yuan, 187.7 billion yuan, 194.9 billion yuan respectively, and that the per capita GDP of Tongliao is 52,788 yuan, 54,487 yuan, 58,077 yuan, 60,545 yuan, 60,160 yuan, 62,468 yuan, respectively. Therefore, according to the formula, we can conclude that the ecological footprint of 2011-2016 years' GDP water resources is 0.0551, 0.0500, 0.0458, 0.0440, 0.0432, 0.0423, and the following dynamic change line maps are obtained:



The dynamic change of line diagram above can clearly show the water resources of the million yuan GDP in Tongliao. The above data shows that the efficiency of water resources utilization in Tongliao has been increasing year by year.

4.4. Comprehensive analysis of water resources carrying capacity in Tongliao

According to the calculation and analysis of the ecological footprint, birth, state surplus (or deficit) of the water resources in the city and the state footprints of the million yuan GDP of water resources, it is found that the water resources are in the ecological deficit and the utilization rate of resources is not high, but the utilization efficiency of water resources is basically increasing year by year.The carrying capacity of water resources in the City has been declining from 2011 to 2013, it has been rising from 2014 to 2011. It can be seen from table 4 and table 10. The agricultural water accounts for the largest proportion followed by industrial water consumption. Therefore, we should pay attention to agricultural water use, improve the technology of irrigation farmland, and change the original flood-style irrigation into underground pipes-style for irrigation. In the next few years, the carrying capacity of water resources of the city will continue to increase and the ecological deficit will continue to decline.

5. Suggestions on the sustainable development of water resources in Tongliao

In view of the existing problems of water resources in Tongliao City, I give some environmental policy suggestions according to my own knowledge.The improvement measures of water resources protection in Tongliao are as follows: (1) the control of urban industrial pollution sources requires command control as a means, and the government needs the government to formulate relevant laws and regulations on urban sewage treatment. (2) In view of the use of pesticides and fertilizers in rural areas, the government should put forward control policies to persuade and encourage farmers not to use pesticides and fertilizers and instead give them additional incentives [7]. (3) the discharge of industrial waste water should meet the standard of the national emission provision. (4) Local, central and provincial environmental protection departments are respectively responsible for approval of all industrial projects. (5) By changing the methods of rural agricultural water irrigation, irrigation

channel lining, rural sewage treatment and other means to save agricultural water and reduce water consumption, and increase the irrigation water source. (6) Tongliao Municipality needs to establish environmental impact assessment and three simultaneous systems, emission permit issuance system, emission charges system, requirements for treatment within a specified period of time, as well as the shutdown of pollution enterprises, the elimination of the implementation of industries, cleaner production audit, listed companies environmental protection verification and other control means [8].

6. Conclusions

Through accounting of the ecological footprint of water resources in Tongliao, we found that the proportion of the first industry and the proportion of the agricultural irrigation water consumption was the largest, and the current situation of the ecological deficit was obvious. The utilization efficiency of water resources was relatively low,the water environment in the region was insecure. At present, there is a shortage of water resources in the city and the serious problem of the low utilization efficiency of water resources. Because of urbanization and accelerated progress of industrialization, the contradiction between the supply and demand of water resources in Tongliao is becoming more and more severe. However, from 2015 the water resources began to change from the original ecological deficit to the ecological surplus. Because of the high usage of water in the city, the water resources carrying capacity of each district is becoming weak. Therefore, it is necessary to adjust the industrial structure of Tongliao, import the external water, improve the utilization of water efficiency, carry out some water saving methods, and improve the ecological carrying capacity of water resources in the city. Tongliao city area is the key base of agriculture in China, and it is also an important producing area of all kinds of grains. Therefore, in the course of development, the city should vigorously develop the water-saving agriculture, change the industrial structure, and make appropriate adjustment to industrial policies and development path for each district.

Acknowledgments

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