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Measurement method of regional water resources carrying capacity based on ecological footprint

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ABSTRACT

Studying water resources carrying capacity is the basis and premise for determining regional socio-economic development, and it is the need to measure the sustainable use of water resources. Based on the ecological footprint (EF) method, the calculation method of regional water resources ecological carrying capacity is proposed, and the macro and micro analysis of water resources carrying capacity in the city is carried out. The results of the macro analysis show that the per capita water EF of the city from 2012 to 2019 is basically stable, with a slight increase overall. The EF of water resources accounts for the largest proportion of the city's EF, but it has decreased from 86.2% in 2012 to 79.0% in 2019. The proportion of aquatic products' EF is rising, rising from 13.75% to 21%. The water ecological carrying capacity of the city is mainly determined by the number of water resources. The micro-analysis results show that in 2019, the city's water resources system showed an ecological loss with a loss rate of 37%. The ecological carrying capacity of water resources is overloaded. The growth of the floating population in the process of urbanization has greater pressure on the ecological carrying capacity of regional water resources.

Keywords: Ecology; Region; Water resource; Carrying capacity; Measurement; Ecological footprint

1. Introduction

The term "capacity" is also known as "carrying capacity". Regional water carrying capacity originates from ecology is used to measure the maximum number of individuals in the particular species under certain regional environment [1]. With the social and economic development of mankind, global resources and the environment are becoming increasingly tense. People gradually realize that natural resources are the material basis of life systems and human development, and their quantity and quality are limited. Their ability to meet the needs of human development now and in the future is also limited [2]. An earlier concept of ecological carrying capacity was proposed by the World Conservation Union, the United Nations Environment Programme and the World Wildlife Fund in its publication protecting the earth [3]. They define carrying capacity as a healthy organism that an ecosystem can support, that is, maintaining its productivity, adaptability and capacity to regenerate [4]. Later, the concept of "capacity" was extended, and it was often used to indicate the limits of the specific activities that ecosystems, environmental systems, and resource systems can withstand [5]. Therefore, many concepts such as ecological carrying capacity, environmental carrying capacity, and resource carrying capacity have also emerged [6].

The evolution and development of the concept of carrying capacity is a response to the problems that arise. There are different concepts and corresponding theories

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at different stages of development [7]. For example, in response to environmental issues, people have proposed the concept and theory of environmental carrying capacity; for the shortage of land resources, land resource carrying capacity has been proposed. The term "water resources carrying capacity" was put forward by Chinese scholars in the late 1980s as the water problem became more and more prominent. The carrying capacity of water resources is an important part of the natural resource carrying capacity of a country or region in the process of sustainable development. It has a crucial impact on the speed and scale of a country's overall development [8]. Since the 1990s, it has been a common consensus to adhere to the path of sustainable development in the social and economic development of regions and countries. Water shortages and water security have also become important factors influencing sustainable development. As a fundamental issue of sustainable development and water security, research on water resources carrying capacity has attracted great attention from the academic community and has become a key and hot issue in current water science [9].

In the theoretical study of Regional Water Carrying Capacity, the results of individual studies are few and most of them are included in the theory of sustainable development. Domestic research in this area started late. A systematic and scientific theoretical system has not yet been formed, and even the definition of regional water resources carrying capacity has not been unified. To this end, this paper studies the measurement methods of regional water resources ecological carrying capacity (WEC) and provides an important theoretical and practical basis for water resources protection [10].

2. Materials and methods

2.1. Calculation method of regional WEC based on ecological footprint (EF) method

2.1.1. Calculation of water EF

Since water has both aquaculture function and purification function, to avoid repeated calculation of aquatic product EF and water pollution EF, relatively large values are selected as the EF generated by the two in the study [11–13].

The Eq. (1) for calculating the water EF is:

$$\mathrm{EF}_{w} = \mathrm{EF}_{\mathrm{fw}} + \max\left(\mathrm{EF}_{\mathrm{ww}}, \mathrm{EF}_{\mathrm{wp}}\right) \tag{1}$$

where, EF_{w} is the saline ecological footprint (hm^2); $\mathrm{EF}_{\mathrm{fw}}$ is the freshwater ecological footprint (hm^2); $\mathrm{EF}_{\mathrm{ww}}$ is the water pollution ecological footprint (hm^2); $\mathrm{EF}_{\mathrm{wp}}$ is the aquatic product ecological footprint (hm^2).

2.1.1.1. EF of aquatic products

The Eq. (2) for calculating the EF of aquatic products is:

$$\begin{aligned}\mathrm{EF}_{\mathrm{wp}} &= N \times \mathrm{AEF}_{\mathrm{wp}} = N \times \gamma_j \times \left(\mathrm{AC}_{\mathrm{wp}} / \mathrm{AP}_{\mathrm{wp}}\right) \\ &= \gamma_j \times \left(\mathrm{TC}_{\mathrm{wp}} / \mathrm{AP}_{\mathrm{wp}}\right)\end{aligned} \tag{2}$$

where, $\mathrm{EF}_{\mathrm{wp}}$ is the aquatic product ecological footprint (hm^2); N is the population; $\mathrm{AEF}_{\mathrm{wp}}$ is the ecological footprint of per capita aquatic products (hm^2); $\mathrm{AC}_{\mathrm{wp}}$ is the per capita consumption of aquatic products (t/person); $\mathrm{AP}_{\mathrm{wp}}$ is the average production capacity of global aquatic products (t/hm^2); γ_{j} is the global waters balance factor; $\mathrm{TC}_{\mathrm{wp}}$ is the total aquatic product consumption (t).

The balance factor is the coefficient required to convert the productivity of different bioproductive land into land productivity with the same organism [14]. Its calculation formula is as follows:

The productive land balance factor of a certain type of ecology = the average ecological productivity of such ecologically productive land in the world/average ecological productivity of all ecologically productive land in the world [15].

2.1.1.2. EF of water resources

The Eq. (3) for calculating the EF of water resources is:

$$\begin{aligned}\mathrm{EF}_{\mathrm{fw}} &= N \times \mathrm{AEF}_{\mathrm{fw}} = N \times \gamma_j \times \left(\mathrm{AC}_{\mathrm{fw}} / \mathrm{AP}_{w}\right) \\ &= \gamma_j \times \left(\mathrm{TC}_{\mathrm{fw}} / \mathrm{AP}_{w}\right)\end{aligned} \tag{3}$$

where, $\mathrm{EF}_{\mathrm{fw}}$ is the urban resource ecological footprint (hm^2); $\mathrm{AEF}_{\mathrm{fw}}$ is the per capita water ecological footprint (hm^2); AP_{w} is the global average water production capacity ($\mathrm{m}^3/\mathrm{hm}^2$); $\mathrm{TC}_{\mathrm{fw}}$ is the amount of water consumption (m^3).

The water consumption is equal to the sum of the amount of water used in living and the amount of water used in production. The Eq. (4) is as follows:

$$\mathrm{TC}_{\mathrm{fw}} = \mathrm{TC}_{\mathrm{lw}} + \mathrm{TC}_{\mathrm{prw}} \tag{4}$$

where, $\mathrm{TC}_{\mathrm{lw}}$ and $\mathrm{TC}_{\mathrm{prw}}$ are the amount of water used in the living and the amount of water used in production (m^3).

2.1.1.3. EF of water pollution

The calculation Eq. (5) for the EF of water pollution is:

$$\begin{aligned}\mathrm{EF}_{\mathrm{ww}} &= N \times \mathrm{AEF}_{\mathrm{ww}} = N \times \left(\mathrm{AC}_{\mathrm{ww}} / \mathrm{AP}_{w}\right) \\ &= \gamma_j \times \left(\mathrm{TC}_{\mathrm{ww}} / \mathrm{AP}_{w}\right)\end{aligned} \tag{5}$$

where, $\mathrm{EF}_{\mathrm{ww}}$ is the ecological footprint of water purification (hm^2); $\mathrm{AEF}_{\mathrm{ww}}$ is the ecological footprint of per capita water purification (hm^2/person); $\mathrm{AC}_{\mathrm{ww}}$ is the amount of per capita water required for dilution and purification of pollution (m^3/person); $\mathrm{TC}_{\mathrm{ww}}$ is the amount of water required to dilute and purify pollution (m^3).

The "EF" is the computational tool used to measure the natural resources consumed for human development [16]. The EF model is mainly used to calculate the bio-production area necessary to maintain resource consumption and waste consumption under a certain population and economic scale. To distinguish it from the common area unit (hectare), the unit of ecological footprint is represented by global hm^2, referred to as ghm^2.

2.1.2. EF Supply–WEC model

The essential characteristics of water resources include three aspects of effectiveness, controllability, and regenerability. Effectiveness means that water that has a utility for socio-economic development and the ecological environment can be considered as water resources. The water resources defined by the validity criteria include the effective part of precipitation and runoff water resources, which is a generalized water resource [2]. In the context of generalized water resources, regional WEC can be expressed as reflecting the various effects of water on various types of land carrying capacity. The sum of different types of land carrying capacity is the regional water resources carrying capacity [17–21]. The calculation Eq. (6) is:

$$\text{WEC} = \sum_{j=1}^{6} B_j = \sum_{j=1}^{6}\sum_{i=1}^{k} w_i \times s_j \times \gamma_j \times y_j \tag{6}$$

where, WEC is the regional water resources ecological carrying capacity; j is the land type; B_j is the carrying capacity of the j-type land consumption project (ghm^2); w_i is the water consumption of the i-type water use project (m^3); s_j is the conversion factor (hm^2 m^{-3}) for the i-type water use project converted to the j-type land area, which is determined by the type of water use and the rate of water use; γ_j is the balance factor of the j-type land; 1111 222 the production factor y_j is the average productivity of the j-type land in a certain area.

2.1.3. Consumption model of water resources EF

The EF represents the consumption of regional residents, and the sum of the different types of resource consumption and the bio-production area required to absorb consumer waste is the regional EF [22,23].

The calculation formula is as shown in (7):

$$\begin{cases} \text{EF} = \sum_{j=1}^{6} A_j = N \times \sum_{j=1}^{6} a_j = N \times \sum_{j=1}^{6}\sum_{i=1}^{n} \gamma_j \times \dfrac{C_{ji}}{P_{ji}} \\ \text{ef} = \text{EF} / N \end{cases} \tag{7}$$

where, EF is the regional ecological footprint of water resources; N is the population (person); j is the land type; A_j is the ecological footprint converted by the j-type land consumption project; a_j is the ecological footprint of per capita water resources converted by j-type land consumption projects; γ_j is the balance factor of j-type land; i is the type of consumption item for different land; C_{ji} is the per capita annual consumption of i-category consumption items of j-category land in a certain area; P_{ji} is the average production of i-type consumption items in j-category land; ef is the per capita ecological footprint of the six types of land water resources.

With the improvement of living standards, residents' consumption of energy and biological resources is increasing, and the EF will have an increasing trend in the existing per capita ecological footprint ef. At the same time, the development and application of science and technology will increase the efficiency of resource utilization, thereby reducing the per capita ecological footprint ef. Under the combined effect of the above two aspects, the EF will fluctuate. Considering the operability of the model, a balanced per capita ecological footprint ef$_0$ is defined to represent the balance between the growth of the per capita EF caused by the improvement of living standards and the decline of the unit EF caused by scientific and technological development.

2.1.4. Evaluation model of water resources ecological security

The EF of water resources measures the bio-productive area of real water resources necessary for human survival. Comparing it with the ecological production area of water resources that can be provided in this area can determine whether the water production and consumption activities in the region are within the loadable range. It measures the sustainable use of regional water resources to ensure regional water security [24,25].

2.1.4.1. Ecological surplus and an ecological deficit of water resources

The ecological surplus of water resources and the ecological deficit indicator can be used to measure the sustainable use of water resources in a region, which characterizes the safety of water resources in a region. The ecological surplus and ecological deficit of water resources are expressed by the EF of water resources generated by the consumption of water resources in the region and the ecological carrying capacity of water resources in the region. That is the difference between the EF of water resources and the ecological carrying capacity of water resources. Its calculation Eq. (8) is as follows:

$$E_\text{rd} = \text{EF}_w - \text{WEC} \tag{8}$$

where E_rd is the ecological surplus and ecological deficit of water resources (hm^2), EF$_w$ is the ecological footprint of water resources. If $E_\text{rd} > 0$, it indicates that the water footprint of the country or region is greater than the ecological carrying capacity of the water resources, that is, the ecological deficit of water resources. This indicates that the water resources in the country or region are not safe. The water resources provided by the natural ecosystems in the region are insufficient to support the population consumption patterns and levels in the region, and regional development is inhibited. Conversely, $E_\text{rd} < 0$ indicates the ecological surplus of water resources, which indicates the water security of the country or region, and the water resources capacity of the region is sufficient to support economic and social development [26,27].

2.1.4.2. Water resources ecological pressure index

The water resources ecological pressure index can also be called the water resources shortage or the water resources ecological pressure intensity, which refers to the ratio of the water EF of a country or region to the ecological carrying capacity of water resources. The index reflects the degree of pressure on the ecological environment of a country or region. The greater the value is, the greater the ecological pressure on the water resources of the country or region is, and the worse the water resources security is.

$$\text{EPI}_w = \frac{\text{EF}_w}{\text{WEC}} \tag{9}$$

where EPI_w is the water resources ecological pressure index. If $\text{EPI}_w > 1$, the water supply in the region is insufficient and sustainable use cannot be achieved. The larger the EPI_w is, the greater the safety pressure on water resources is. If $\text{EPI}_w = 1$, the supply and demand of water resources in the region will be balanced, and water resources security will be in a critical security state or basic security; if $0 > \text{EPI}_w > 1$, the water supply in the region is greater than the consumption, and the development and utilization of water resources are relatively safe. As an indicator of the sustainable use of water resources, the water resources ecological stress index is used to measure the lack of water resources. As an indicator of the sustainable use of water resources, the ecological stress index of water resources is used to measure the lack of water resources. It organically combines the ecological carrying capacity of regional water resources with the water consumption and the water demand of the ecological environment to quantitatively analyze the safety status of water resources.

2.1.4.3. Water resources EF intensity

The water resources EF intensity is also called the 10,000 yuan gross domestic product (GDP) EF. It refers to the ratio of the water resources EF within the region to the regional GDP. It characterizes the level of water use efficiency. The ecological intensity of water resources is obtained by dividing the EF of water resources by the GDP of 10,000 Yuan. The greater the value is, the more the EF of water resources consumed by the 10,000 Yuan of GDP is. This shows that water use efficiency is low and water resources are not safe.

$$\text{EFI}_w = \frac{\text{EF}_w}{\text{GDP}} \tag{10}$$

2.2. Subjects

This study takes a city as the test object. The city has an area of 5,818 km^2 and a population of 2.58 million. The average annual water resources are about 3.946 billion, and the per capita water resources are 1,537 m^3, which is lower than the national average. There is an important river in the city. The water quality test results show that the river has good water quality, but there are still some degrees of pollution in some river sections, especially in the eastern plain river network area [28,29]. The main pollution indicators affecting river water quality are ammonia nitrogen, total phosphorus and biochemical oxygen demand. Among all water quality monitoring sections in the city, the proportions of end face meeting the water quality standards of Class I, Class II, Class III, Class IV and Class V are 0.0%, 18.9%, 51.4%, 13.5%, and 8.1%, respectively. Sections of inferior V water quality standards accounted for 8.1%, and sections that do not meet the functional requirements of waters account for 31.1%. In this paper, the measurement of water resources carrying capacity in this region is mainly macro and micro. The macro analysis is based on the water ecological carrying capacity of the city from 2012 to 2019, while the microanalysis is based on the water resources carrying capacity of the city in 2019.

3. Results

3.1. Macro analysis

According to the calculation formula of water EF, the results of water EF of the city from 2012 to 2019 are calculated as shown in Table 1.

According to the above table, the per capita water EF of the city from 2012 to 2019 is basically stable and at (0.72–0.8) hm^2/person, but overall it has increased slightly.

Due to the better water quality in the city, the per capita water pollution EF is lower than the aquatic product footprint. Therefore, according to the water EF model, the larger aquatic product footprint is selected in the aquatic product footprint and per capita water pollution footprint, and is added to the water resources footprint to get the water EF. The composition of the city's water EF from 2012 to 2019 is shown in Fig. 1.

It can be seen from Fig. 1 that the largest proportion of the water EF of the city is the EF of water resources, but its proportion is shrinking year by year, from 86.2% in 2012 to 79.0% in 2019. The proportion of aquatic products' EF is rising, from the initial 13.75% to 21% in 2019. The reason for this situation is that the city's aquatic product consumption has been increasing from 2012 to 2019, while water consumption is declining. As a result, the absolute value and proportion of aquatic products' EF have increased, while the proportion of water resource's EF is large but gradually decreasing.

According to the method of this paper, the water ecological carrying capacity of the city from 2012 to 2019 is calculated. The results are shown in Table 2.

According to the above table, in 2014, the total amount of water resources was 4.67 billion, and the city's water ecological carrying capacity was also the largest, reaching 657.65. It shows that the water ecological carrying capacity of the city is mainly determined by the number of water resources. The changing trend varies with the number of water resources, and the impact of precipitation is very large, so there is a large fluctuation.

3.2. Microscopic analysis

To deeply measure the city's water resources carrying capacity, the city's 2019 water resources application data was extracted. According to the city's 2019 water resources bulletin, the water use projects include urban domestic water, urban public water, ecological environment water, industrial water, farmland irrigation water, forestry and fishing water. In combination with the economic output of water resources consumption, the conversion land type is determined by the benefit equivalence method, as shown in Table 3.

Table 1
Water EF of the city from 2012 to 2019

Particular year		2012	2013	2014	2015	2016	2017	2018	2019
EF of aquatic products	Aquatic product (ten thousand *t*)	13.57	14.4	15.19	16.69	17.3	17.84	19.04	21.27
	Water area for aquaculture (ten thousand hm^2)	75.37	80	92.76	92.76	96.1	99.1	105.79	118.2
	EF of aquatic products (ten thousand hm^2)	26.38	28	32.46	32.46	33.64	34.69	37.03	41.36
	Per capita EF of aquatic products (ten thousand hm^2)	0.1	0.11	0.13	0.13	0.13	0.13	0.14	0.16
Water resources EF	Total water consumption (billion m^3)	10.01	9.95	9.27	9.27	9.63	8.76	9.49	9.43
	Water resources EF (ten thousand hm^2)	165.45	164	153.2	153.22	159.2	144.8	156.86	155.9
	EF of per capita water resources (ten thousand hm^2)	0.65	0.64	0.6	0.6	0.62	0.56	0.61	0.6
EF of water pollution	COD emissions (*t*)	29,085.6	34,028.0	31,204	27,739	22,299	22,393	22,276	21,144
	Demand for pollution dilution and purification (ten thousand hm^3)	1,692.84	2,051	1,881	1,671.9	1,344	1,350	1,342.7	1,274
	EF of water pollution (ten thousand hm^2)	2.8	3.39	3.11	2.76	2.22	2.23	2.22	2.11
	Per capita EF of water pollution (hm^2/people)	0.011	0.01	0.012	0.011	0.009	0.009	0.009	0.009
Water EF (ten thousand hm^3)		191.83	192	194.5	185.68	192.8	179.5	193.88	197.2
Per capita water EF (hm^2/people)		0.75	0.75	0.76	0.72	0.75	0.8	0.75	0.77

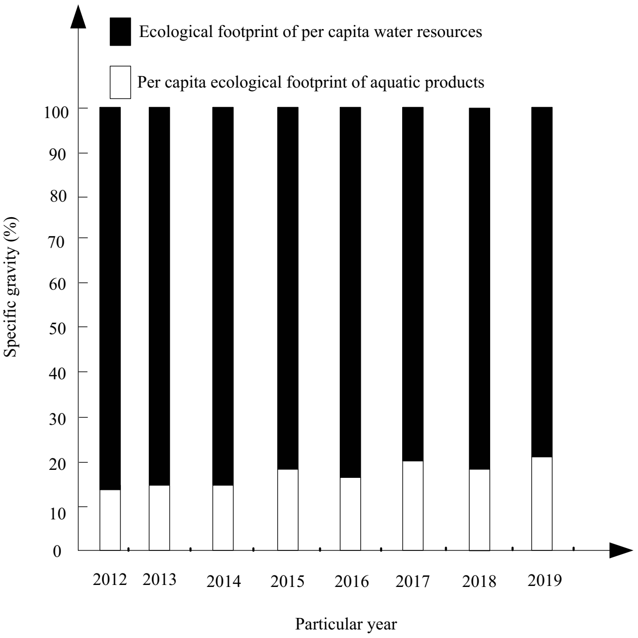

Fig. 1. Composition of the water EF of the city from 2012 to 2019.

According to the relevant statistics of the city's water quota (trial) and statistical yearbook in 2019, the per capita land area is calculated to be 0.0081 hm^2 person^{-1}. According to the water quota for hydropower generation, the industrial water consumption is converted into electric energy, and it is converted into forestland production by the resource substitution method. Finally, according to the conservation of energy, the land area of fossil energy is calculated. Detailed data are shown in Table 4.

In the city's 2019 statistical yearbook, according to the consumption composition of the residents and the municipal public green space, the household consumption items related to water consumption are screened out, and the land type of the consumption raw materials is determined. Clothing, household equipment, services, transportation, communications, education, culture, entertainment, electricity, and other industrial products are converted into fossil energy land. Garden green space, built-up areas and parks are all calculated based on actual area and land type. Detailed data are shown in Table 5.

3.2.1. Contribution rate of WEC

According to the data of Tables 3–5, the ratio of the ecological capacity of the unit water to the overall water resources carrying capacity is calculated as the contribution rate of each water item. The calculated data are shown in Table 6.

It can be seen from the above data that the two major contributions to the regional WEC are urban domestic water and farmland irrigation water, the smaller ones are the ecological environment and urban public water, and the intermediate level is the water for industrial and forestry, animal husbandry and fishery. Urban domestic water consumption contributed the most to the city's regional water resources ecological load, accounting for 61.73%. This shows that in the process of urbanization, the population (resident population

Table 2
Water ecological carrying capacity of the city from 2012 to 2019

Particular year	Total water resources (Billion m^3)	Water ecological carrying capacity (ten thousand hm^2)	Per capita ecological carrying capacity (ten thousand hm^2)
2012	25.28	356.00	1.39
2013	33.37	469.93	1.83
2014	46.70	657.65	2.56
2015	21.35	300.66	1.17
2016	23.40	329.53	1.28
2017	29.63	417.26	1.62
2018	28.63	403.18	1.56
2019	33.64	473.73	1.84

Table 3
Water consumption, water quota and converted land categories of a City in 2019

Water item	W (water consumption)	Numerical value	Company	Converted category
Town life	11,398.3	0.25	L (people d)$^{-1}$	Construction land
Town utilities	3,898.66	1.7	L (m^2 d)$^{-1}$	Woodland
Ecological environment	173.36	1.3	L (m^2 d)$^{-1}$	Grassland
Industry	14,500	1,000	m^3 (10^4 kWh)$^{-1}$	Fossil energy
Farmland irrigation	13,192.2	4,500	m^3 (hm^2 a)$^{-1}$	Cultivated land
Forestry, animal husbandry and fishery	2,101	2,700	m^3 (hm^2 a)$^{-1}$	Woodland

Table 4
Calculation of ecological carrying capacity of water resources in 2019

Water item	Converted category	S (Conversion coefficient)	Per capita supply area/hm^2	γ (Equilibrium coefficient)	Y (Yield factors)	Ecological carrying capacity of water resources
Town life	Construction land	7.4	0.058	2.82	2.24	0.37
Town utilities	Woodland	1.61	0.0043	1.1	1.2	0.0057
Ecological environment	Grassland	2.1	0.00025	0.54	3.29	0.00045
Industry	Fossil energy	2.83	0.028	1.14	1.3	0.042
Farmland irrigation	Cultivated land	2.22	0.02	2.82	2.24	0.13
Forestry, animal husbandry and fishery	Woodland	3.7	0.0053	1.1	1.2	0.0071
Total						0.55

and floating population), mainly the growth of floating population, has greater pressure on the ecological carrying capacity of regional water resources in the city; The urban public water contributes the least to the urban WEC of the city, which is 2.81%. This indicates that the urban public water has less pressure on the regional WEC and can alleviate the city's water resources ecological carrying pressure to some extent.

3.2.2. Ecological profit-loss and the profit-loss ratio of ecological bearing capacity of water resources in regions

Ecological profit-loss and the profit-loss ratio of ecological bearing capacity of water resources in regions are calculated by the proposed method. The results are shown in Table 7.

The ecological carrying capacity of the city's water resources is 0.55 ghm^2 person^{-1}, and the EF of human consumption of water resources in the city is 0.76 ghm^2 person^{-1}. Overall, the city's water resources system showed an ecological loss with a deficit of 0.21 and a loss rate of 37%. According to relevant resources, with the development of society, the city's per capita utilization of ecological capacity (ecological supply) is declining. Therefore, with the intensification of the water crisis, the city's water supply has gradually decreased. The calculation results in this paper are basically in line with the actual situation of the city's economic and social development.

Table 5
Calculation of ecological carrying capacity of water resources in 2019

Consumption indicators	Company	Annually average	Converted category	Real estate value	Equilibrium coefficient	Per capita footprint
Food	Element	4,732.44	Cultivated land	64,701.24	2.82	0.206
Clothing	Element	760.92	Fossil energy	22,272.97	1.14	0.039
Household equipment, supplies, and services	Element	696.84	Fossil energy	22,272.97	1.14	0.036
Transport and communications	Element	3,599.04	Fossil energy	22,272.97	1.14	0.186
Educational, cultural and entertainment services	Element	1,900.92	Fossil energy	22,272.97	1.14	0.0976
Live	Element	1,376.76	Construction land	216,761.86	2.24	0.015
Garden green space area	hm^2	4,741	Grassland	4,401.68	0.54	0.0018
Area of built-up area	hm^2	10,805	Construction land	216,761.86	2.82	0.021
Park area	hm^2	1,030	Grassland	4,401.68	0.54	0.00038
Electricity consumption	kWh	721.434	Fossil energy	22,272.97	1.14	0.16
Total						0.76

Table 6
Contribution rate of the ecological carrying capacity of water resources in 2019

Water item	Water consumption	Ecological carrying capacity of water resources	Unit water carrying capacity	Contribution rate
Town life	11,398.3	0.37	46.77	61.73
Town utilities	3,898.66	0.0057	2.13	2.81
Ecological environment	173.36	0.00045	3.74	4.94
Industry	14,500	0.042	4.19	5.53
Farmland irrigation	13,192.2	0.13	14.04	18.53
Forestry, animal husbandry and fishery	2,101	0.0071	4.89	6.45
Total	45,263.53	0.55	17.64	100

4. Discussion

Based on the research content of this paper, the following countermeasures are proposed for the sustainable development of ecological water resources in the future:

4.1. Reduce water resource consumption and increase water reuse rate

At present, the average use efficiency of water resources in each administrative region is lower than that of developed countries, and there are different levels of water waste, especially in places where water resources are relatively abundant, and the water reuse rate is low. To this end, it should strengthen the reuse of water resources, strengthen relevant supervision functions, establish a dynamic supervision system, and achieve dynamic management of water resources to reduce water consumption and improve water use efficiency.

4.2. Preventing water pollution and accelerating the construction of water resources protection system

In recent years, water pollution has seriously affected the normal social and economic development of the region, and the utilization rate of sewage treatment is not high, which has aggravated water pollution. Therefore, water resources protection policies should be established and improved, the leadership responsibility system should be strengthened, and the new situation of water resources protection and social harmonious development should be gradually established. First, we must formulate water conservation plans and implement them with economic, administrative, and legal; secondly, it is necessary to control pollution sources, adopt advanced technology, improve resource utilization, and reduce the direct discharge of wastewater in the production process. Also, it is necessary to strengthen the protection of drinking water, to draw up drinking water resource protection zones, and to take practical measures to protect drinking water from pollution and ensure the quality of drinking water.

4.3. Further, strengthen the construction and implementation of water resources regulations

The legal system propaganda should be strengthened, and the construction of a water-saving society should be regarded as one of the key points in the construction of a harmonious society so that people can understand and participate in the construction. The people's awareness of water

Table 7
Ecological profit-loss and the profit-loss ratio of ecological bearing capacity of water resources in regions

Converted category	Per capita footprint	Per capita carrying capacity	Per capita profit and loss	Profit-loss ratio
Cultivated land	0.206	0.13	–0.076	–0.58
Fossil energy	0.5186	0.042	–0.48	–11.35
Construction land	0.0356	0.37	0.33	0.9
Grassland	0.00218	0.00045	–0.0017	–3.84
Woodland		0.013	0.013	1
Total	0.76	0.55	–0.21	–0.37

conservation should be strengthened to achieve the goal of building a water-saving society. The people's awareness of water conservation should be strengthened to achieve the goal of building a water-saving society. It is necessary to act under objective laws and achieve rational development and utilization of water resources, and its scale must meet the requirements of sustainable development.

4.4. Improve water price and market system

The local water price system also has a great impact on the waste of water resources. At present, domestic water fees are much lower than sewage treatment costs, which have led some companies to directly exploit groundwater or use existing surface water resources. The recycling rate of industrial water resources is low, and sewage treatment is rare. To this end, we should improve the market system of water prices, increase the reuse rate of water resources, encourage enterprises to carry out sewage treatment and give relevant policy support and preferential treatment. It is necessary to reform the current water resources management system to achieve intensive management under market economy conditions. Finally, it is necessary to formulate reasonable water prices and use economic levers to adjust water consumption so that water resources can be used rationally, thereby improving water resource utilization.

5. Conclusions

In this paper, based on the EF method, the calculation method of the regional WEC is used to measure the water carrying capacity of a city. The measurement results show:

- The per capita water EF of the city from 2012 to 2019 is basically stable and at (0.72–0.8)hm^2/person, but overall it has increased slightly;
- The largest proportion of the water EF of the city is the EF of water resources, but its proportion is shrinking year by year, from 86.2% in 2012 to 79.0% in 2019. The proportion of aquatic products' EF is rising, from the initial 13.75% to 21% in 2019;
- The size of the water ecological carrying capacity of the city is mainly determined by the number of water resources;
- Urban domestic water consumption contributed the most to the city's regional water resources ecological load, accounting for 61.73%. This shows that in the process of urbanization, the population (resident population and floating population), mainly the growth of floating population, has greater pressure on the ecological carrying capacity of regional water resources in the city;
- The ecological carrying capacity of the city's water resources is 0.55 ghm^2 person^{-1}, and the EF of human consumption of water resources in the city is 0.76 ghm^2 person^{-1}. Overall, the city's water resources system showed an ecological loss with a deficit of 0.21 and a loss rate of 37%.

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