Scholar Publishing Group
Academic Journal of Environmental Biology
https://doi.org/10.38007/AJEB.2021.020202
ISSN 2789-8407 Vol. 2, Issue 2: 12-20

Evaluation of Water Resources Carrying Capacity based on Ecological Footprint

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Keywords: Ecological Footprint, Water Resources Carrying Capacity, Water resources Utilization, Ecological Evaluation

Abstract: Water resources(WR) have gradually become a key factor affecting the stable expand of social economy. In this context, it is of great practical significance to evaluate and simulate the regional WR carrying capacity(CC), analyze the WR CC, and find the shortcomings of the current WR system. This paper mainly studies the evaluation of WR CC based on ecological footprint(EF). In this paper, the concept of WR CC is expounded and the calculation formula of water EF is analyzed. The EF model was used to calculate the EF and CC of WR in A city. The study of WR CC has important theoretical and practical significance for the scientific and rational expand and utilization of local WR, economic expand, environmental protection, ecological balance and harmony between man and land.

1. Introduction

At present, China has become one of the largest economies in the world. In the past 30 years, with rapid economic and social development(SC), the demand for WR has also increased, the contradiction between supply and demand of WR has become increasingly serious, and various economic, social and natural environmental problems caused by the relative shortage of WR have gradually become prominent [1-2]. According to relevant research, more than 400 cities in China are facing imbalance between water supply and demand. The over-exploitation of WR also leads to environmental problems such as ecological degradation. Therefore, our country has increased the dynamics of ecological environment governance in recent years, and put forward the green expand idea of "clear water and green mountains are golden and silver mountains". In this context, how to evaluate the CC of WR based on ecological priority has become a key issue in the scientific research of WR and water environment. Domestic scholars define WR CC as the maximum capacity of local WR system to support economic and SC under existing scientific and technological conditions on the premise of sustainable expand. WR CC of a region is a comprehensive index that changes with the level of economic and SC and scientific and technological conditions of the region. Based on the connotation of WR CC, the scientific evaluation of WR CC can be used as a basis to measure the matching degree between local economic and SC level and WR system. If the WR system cannot support the local economic and SC, the stability of the WR system will be affected, which will affect the economic and SC, ecosystem security and biodiversity, etc. [3-4].

With the rapid expand of economic globalization, the research on the quantity and quality of WR is also increasing with the increase of water shortage, and the concept of CC is introduced into the field of WR [5]. The main representative results are as follows: water availability, water quality, sewage treatment and other indicators are used as the influencing factors of urban WR CC, and the WR CC of different cities is analyzed and studied [6]. The CC of urban WR is researched from the Angle of supply and demand balance. The index "WR supply and demand ratio" was used to evaluate the current WR in the Ebro basin and its future ability to meet the water needs of residents in daily life, agriculture and environment [7].

At present, the problem of WR is becoming more and more serious, and has become a restriction factor for the high-quality expand of cities. The study of regional WR CC is not only helpful to clarify the relationship between WR and economic, social and environmental factors, but also of great significance in implementing the strictest WR management system and promoting the efficient and intensive use of WR.

2. WR CC and EF

2.1. WR CC

For the research on WR CC, the theoretical basis can be summarized as the following four points:

(1) Ecohydrological cycle theory

Research on WR CC is based on the hydrological cycle of WR system itself, that is, WR system has the inherent characteristic of self-circulation, which can realize self-repair and self-supplement of WR [8]. However, nowadays, WR have been closely linked with social and economic expand and deeply affected by human activities, so that the original simple self-circulation process of WR system has been changed. Human activities not only interfere with the natural hydrological system cycle, but also change the quantity and quality of WR. Today, the natural water circulation system has become a natural - artificial dual drive circulation system. The basic theory of WR CC is to add the theory of ecohydrological cycle influenced by human activities to the natural water circulation system.

(2) Theory of optimal allocation of WR

At present, human beings are generally faced with the problem of insufficient WR in the process of expand, which is the contradiction between the economic and SC and the insufficient WR supply of the ecosystem itself. Human expand has unlimited demand for WR, but WR themselves are scarce, highly unbalanced in spatial and temporal distribution, and difficult to replace, which will inevitably lead to excessive expand and utilization of WR and the destruction of WR system homeostatic, resulting in a series of ecological and environmental disasters [9]. Therefore, in order to ensure the long-term expand of human society, it is necessary to continuously optimize the allocation of WR, promote the efficient use of WR, and improve the contradiction between supply and demand of WR.

Theory of sustainable expand

WR CC is a subject of economic, ecological and population participation, and each participating unit interacts and influences each other. Resource constraints is always an important point of the solution to this problem, sustainable expand itself is emphasized that comply with the natural laws of expand of WR, efficient and intensive utilization of WR, ensure the expand of population, economic scale, maintain the stability of water cycle, in the long run, should pay attention to promoting rational utilization of WR, guarantee the sustainable expand of the offspring of the WR demand. Therefore, the theory of sustainable expand is the theoretical basis for the research of WR CC [10].

(4) socio-economic-ecological coupling theory

WR CC is based on sustainable expand as the basic principle, on the premise of not destroying WR, under a specific socio-economic scale and technological level can carry the population scale and socio-economic level. From the concept, it can be found that the natural and social characteristics of WR CC, population, economy and WR interweave, forming a multi-level, multi-structure coupling system. In this system, WR, as the most basic material foundation, strongly supports human production and life, and the gradual expand of human beings also affects the CC of the original WR system. The CC of WR has the property of dynamic change. When the human production and life style are optimized intensively, the CC of WR will increase continuously. If human activities continue to destroy, pollute and waste WR, the CC of regional WR will be significantly reduced. At present, the shortage of WR in human expand always reminds us to put WR into the coupled system of "socio-economy-ecology" to promote the harmonious coexistence of human beings and ecology.

2.2. The Concept and Connotation of Water EF

EF theory is a method to analyze the function of life service system based on quantitative methods, which represents the ecological and productive area generated by all the consumption and resources and consumption of the population in any region [11-12]. The EF of WR and water environment can be described in two aspects: one is the WR consumed by human beings in life and production; the other is the process of maintaining the water demand of natural environment. According to the concept of EF, a WR account including surface water, namely, groundwater related to the ecological environment and social and economic functions of WR, is established [13-14]. WR and water environment, as two important indexes to calculate water EF, play a crucial role in water EF. In the water EF model, there are three types of accounts, namely, aquatic product footprint (refers to the productive land area of WR occupied by aquatic products consumption), water resource EF, and water environment EF. Each account also includes water EF, water ecological CC and water ecological profit and loss. Concepts derived from water EF include water EF of ten thousand yuan GDP and per capita water EF [15].

The consumption of WR by agricultural production is called agricultural water EF [6]. Agricultural irrigation water consumption is affected by the current water use, climate, soil, crops, farming methods, irrigation level, canal utilization coefficient and other factors. The calculation formula is as follows:

$$EF_a = a_w \times (A / P_w) \quad (1)$$

In Formula 1, EFa-- agroEF (HM2); Aw Water global equilibrium factor; A- total agricultural water consumption (M3); Pw- Global average productivity of WR (i.e., global average production)(m3/hm2).

The EF of industrial water mainly refers to the EF of water used by various sectors of industrial and mining enterprises in the process of industrial production, such as manufacturing, processing, cooling and washing. The calculation formula of the EF of industrial water is as follows:

$$EF_i = r_w \times (I / P_w) \tag{2}$$

In Equation 2, EFi-- industrial water EF.

The EF of domestic water refers to the EF of urban residents, public water consumption and rural domestic water consumption [17]. These include: urban residents, public buildings, municipal, fire and other water. Rural domestic water includes domestic water for residents and livestock. The calculation formula of EF of domestic water is as follows:

$$EF_l = r_w \times (L / P_w) \tag{3}$$

In Equation 3, EFl-- EF of domestic water (HM2).

EF refers to the amount of water required to maintain the normal operation of ecological environment.

$$EF_s = r_w \times (S / P_w) \tag{4}$$

Considering the above calculation formula and the research objective of this paper, the footprint of aquatic products is not included in the water EF, so the calculation model of the total water EF is as follows:

$$EF_w = EF_a + EF_i + EF_l + EF_s \tag{5}$$

Load index commonly used WR evaluation in the load status of WR of drought and a half thousand dryland area, through the calculation of rainfall, the population of a region, regional GDP and irrigation area of relation with the ratio between the amount of WR in this area, so as to reflect the expand and utilization of regional WR present situation and future expand and utilization of the ease of [18]. Water resource load index is of great significance to the sustainable expand and utilization of WR in a region. As shown in Table 1, water resource load index can be divided into 5 levels, and its calculation formula is as follows:

$$c = k\sqrt{PG} / W \tag{6}$$

Where: C is water resource load index; P is population (10,000); G is gross regional product (ten thousand yuan); W is the total WR (10,000 m^3); K is the coefficient related to precipitation.

Table 1. Classification of WR load index

Water resource load index	Level	Utilization degree of WR
>10	1	Very high
5-10	2	High
2-5	3	Secondary
1-2	4	Lower
<1	5	Low

3. Analysis of WR CC in A City based on EF

3.1. Ecological Environment of A City

The temperature in city A has A large spatio-temporal difference. On the spatial scale, the air temperature is relatively high in the northwest and relatively low in the southeast. The temperature in plain area and river valley is relatively high, while the temperature in mountain and hilly area is relatively low. On the time scale, the minimum temperature in the whole region appears in January, and the monthly average temperature. 8. C to 15 ℃; The highest temperature occurs in July and August, with the monthly average temperature ranging from 13℃ to 23℃. There are up to four months of sub-freezing (November, December, January and February) and 240 days above freezing throughout the year.

The annual average precipitation in the area is 368.5 mm, and the annual evaporation is about 1500mm. In terms of time, the precipitation mainly concentrated in spring and summer (114.3 mm and 127.7 mm, respectively), and less in autumn and winter (62.3 mm and 42.1 mm, respectively). The snowfall period is from October to March of the following year, accounting for about one-third of the annual precipitation. Spatially, the precipitation in the valley region is more in the east than in the west, and more in the mountain region than in the plain. The evaporation drop ratio gradually decreased from west to east.

The river flow in A city changes significantly with the seasons, the annual 6.8 month is the wet season, December to February the next year is the dry season; The melting of snow and ice in April and May each year is easy to form spring flood, while the melting of snow and ice in July and August often forms summer flood. There are a large number of glaciers in the high mountain area of the region, and the distribution area can reach 2078km2. The groundWR in the area are also very rich, and the recoverable amount reaches 26.36 ×106m3, mainly distributed in the plain area. The main recharge sources of surface water system are the melting of alpine snow and ice, atmospheric precipitation and mountain groundwater. The hydropower resource reserves are 705.26 x 104kW ћ, and the annual electricity production is 1509.91 x lOSkw ћ.

3.2. Calculation and Analysis

The calculated data are taken from the Statistical Yearbook of A City, and the county records of all counties and cities in A city area are referred to. Some data are taken from government work reports, field investigations and other relevant reports.

The above data are collected and sorted out, and the relevant water EF calculation formula and WR CC formula quoted in this paper are used to calculate the WR ecological CC of A city.

4. Statistics and Analysis of Calculation Results

4.1. EF of WR

Table 2. Total EF of WR

	2016	2017	2018	2019	2020
Water EF	670145	674173	681478	679042	701842

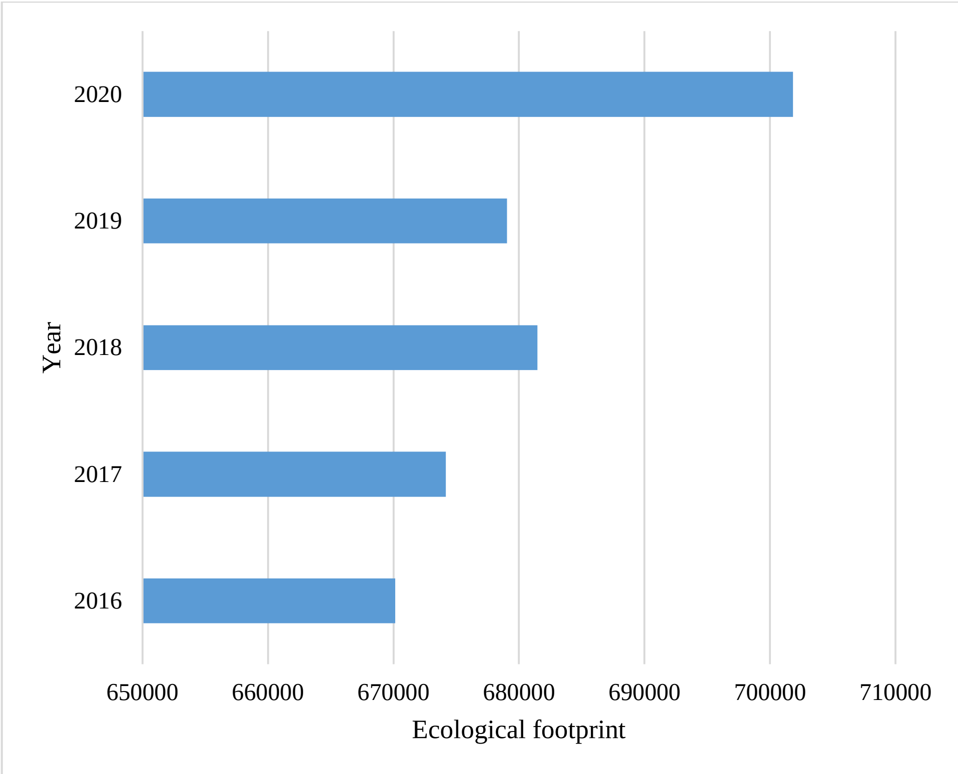

Figure 1. Statistical map of EF of WR

As shown in Figure 1 and Table 2, are the ecological statistics of WR of City A in recent five years. It can be seen from the figure that the total EF of WR in City A shows A trend of fluctuation and rise, with the maximum value being 701842hm2 in 2020 and the minimum value being 670145hm2 in 2016. Since production water accounts for most of the total WR utilization, the total water resource footprint is highly correlated with the production water footprint. The economic and SC of A city has been relatively fast in the past two years.

4.2. CC of WR

Table 3. WR CC

	2016	2017	2018	2019	2020
Water EF	973819	1482105	1216429	1185625	996301

As shown in Figure 2 and Table 3, although the resource CC of city A fluctuates, the overall trend is in A relatively stable range, with A continuous downward trend after 2017. The peak occurred in 2017, which was 1482105hm2. Because of the high precipitation and the large total WR in this year, the CC showed an increasing trend. And the lowest value appeared in 2016, which was 973819hm2.

In general, the WR in City A are relatively sufficient, the CC of WR is large, and the ecological surplus is sufficient. There is considerable potential for the expand and utilization of WR, which can be continuously developed and utilized in A limited way.

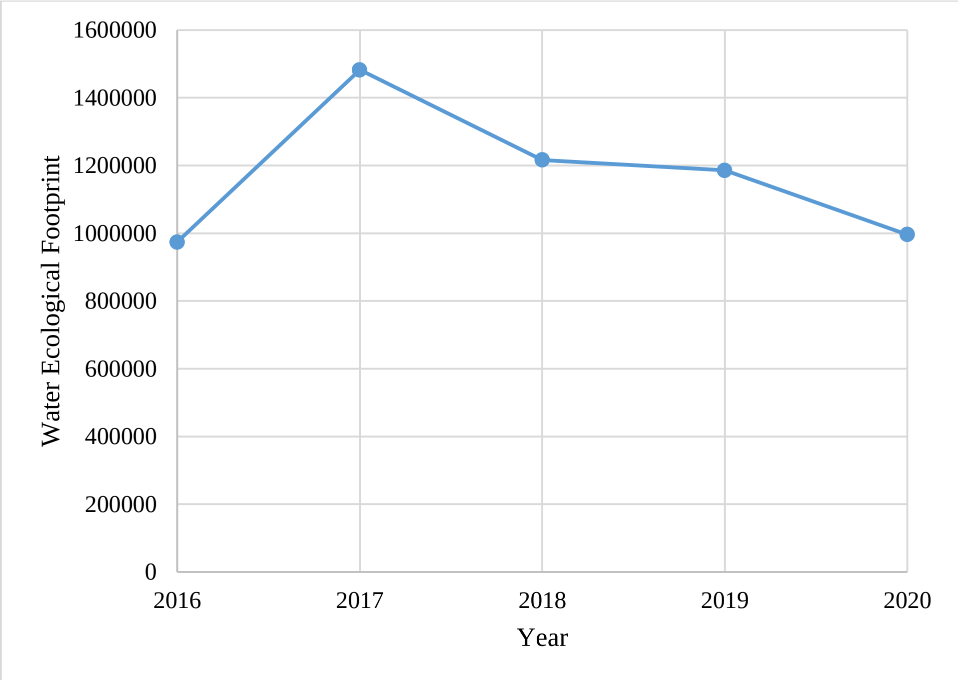

Figure 2. Statistical map of WR CC of city A

5. Conclusion

The research and evaluation of resource and environment CC involves many fields, including management, ecology, sociology, economics, resource science and so on. Under the circumstances of prominent contradiction between man and land, serious destruction of ecological environment, resource shortage, sustainable expand has become the goal of human expand, the research on the comprehensive CC of resources and environment has become a hotspot for scholars. By reading A lot of literature, collecting and sorting out relevant data, this paper analyzes the research status and expand trend of WR CC and EF theory at home and abroad, and uses EF model to calculate the EF and CC of WR in A city.

Funding

This work was supported by the Youth Project of Hunan Education Department(Grant NO.20B394), the Social Science Foundation of Hunan Province of China (Grant No.18JD54) and the Project of Hunan Province Social Science Achievement Review Committee, China (Grant No.XSP20YBC158) .

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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