Ecological footprint and carrying capacity change analysis on Yan'an water resources

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Abstract: Based on the water resource data and economic data from 2006 to 2017, this paper analyzes the temporal and spatial variation characteristics of sustainable water resources utilization in Yan'an, using a water ecological footprint model and the ten-thousand-yuan GDP water resource ecological footprint, combined with the ecological carrying capacity and ecological deficit principle. The result shows that the overall wave of the water resources ecological footprint in Yan'an rises but not in an obvious way, but the ecological carrying capacity and the ecological deficit of water resources are fluctuating. Production water accounts for the largest proportion in the water resources ecological footprint. Affected by industrial transformation, the industrial water consumption in Yan'an has increased year by year and ranked the first by exceeding agricultural irrigation water in 2009. The ecological footprint of water resources in Yan'an has always been greater than its ecological carrying capacity, and the water supply has been in an ecological deficit state; in general, the ten-thousand-yuan GDP water resources ecological footprint has decreased obviously, while the resource utilization has gradually been increasing. However, consumption on water resources by economic development is still faster than resource regeneration.

1. Introduction
Water resources are necessary for human life and development and serve as an important natural resource for social sustainable development. However, one third of the world's population have a drinking water problem. China is a country suffering from severe drought and water shortage. Its freshwater resource accounts for 6% of global water resources, but the per capita water resources only account for 1/4 of the world average level[1]. Ecological footprint, brought forward by Rees, Wackerngel and other scholars [3][4] in 1992, is a comprehensive measuring method used for estimating the sustainable utilization of resources [2]. The built water resource ecological model is used to reflect the stress situation of human survival and development on natural ecology [9] and is mainly applied in the analysis of sustainable utilization of regional resources [10, 11]. By establishing a water resources account, Huang Linnan and other scholars [5] further divide the water resources account into three sub accounts, which makes up for the limitation of water resources function description caused by water areas in this method. The derived water resource ecological footprint models also have many shortcomings in its application. For example, most of these models do not take into account the spatial and temporal changes [6], and the data for calculating parameters is lack of time update [5], which leads to a large error in the calculation result and the prediction accuracy which needs to be improved.

Yan'an is located in Shaanxi province, the overall analysis of Yan'an mainly happens to research objects including the loess plateau or the northwest area. This paper establishes a water resources...
ecological footprint model for the single research object—Yan’an, combines with multiple index to analyze and calculate the data from 2006 to 2017 of Yan’an, in an attempt to provide theoretical guidance for the development and utilization of Yan’an water resources in the future as well as decision basis for the city’s sustainable development.

2. Overview of the research area
Yan’an is located in the northern part of Shaanxi Province and in the midstream of the Yellow River, with a total area of $3.7 \times 10^5$ km$^2$ ($35\degree 20'37'' - 37\degree 29'29'' N, 107\degree 38'57'' - 110\degree 32'44'' E$). The terrain is high in the northwest and low in the southeast and situated in the gully region of the Loess Plateau, with a large population and fragile ecological environment.

3. Research methods and data sources

3.1. Water resources ecological footprint model
Ecological footprint is a model for calculating the sustainable use of resources, measuring the supply and demand of biological resources in a certain region and evaluating the sustainable development of a country, region and even the world in combination with resource carrying capacity, so as to formulate economic and environmental policies and provide theoretical guidance for promotion of ecological civilization construction$^{[12]}$.

Based on the research results of Huang Linnan and other researchers$^{[5]}$, according to the connotation of water resources ecological footprint and water use characteristics, this paper divides water in Yan’an into production water, domestic water and ecological water. The calculation formula is as follows:

$$EF_w = N \times ef_w = N \times \gamma_w \times (W / P_w)$$  \hspace{1cm} (1)

Wherein $EF_w$ is the ecological footprint of water resources (hm$^2$); $N$ is the total population; $ef_w$ is the ecological footprint of per capita water resources (hm$^2$ per capita); $\gamma_w$ is the global equilibrium factor of water resources; $W$ is the consumption amount of water resources per capita (m$^3$); $P_w$ is global average production capacity of water resources (m$^3$/hm$^2$).

3.2. Water resources ecological capacity model
The ecological carrying capacity of water resources is the support which regional water resources can provide to maintain human survival and sustainable social development. Studies have shown that$^{[7,8]}$ in the calculation of water resources carrying capacity, 60% of water resources should be reserved to maintain the ecological environment and maintain ecological balance. In calculation, a factor of 0.4 needs to be multiplied. The calculation formula for the water resources carrying capacity is as follows:

$$EC_w = N \times ec_w = 0.4 \times \psi \times \gamma_w \times Q / P_w$$  \hspace{1cm} (2)

Wherein $EC_w$ is water resource carrying capacity (hm$^2$); $N$ is the total population; $ec_w$ is per capita water resources capacity (hm$^2$ per capita); $\psi$ is the production factor of regional water resources; $\gamma_w$ is water resources global balance factor; $Q$ is water resources total quantity (m$^3$); $P_w$ is the global average production capacity of water resources (m$^3$/hm$^2$).

3.3. Water resources ecological surplus/deficit
The ecological surplus/deficit of water resources is often used to assess the sustainable use of water resources in a country or region$^{[7,13]}$. It is the difference value between the water resources carrying capacity and the water ecological footprint and is the measurement of whether water consumption is within the carrying range in a certain region. Its calculation formula is as follows:

$$EB_w = EC_w - EF_w = N \times (ec_w - ef_w)$$  \hspace{1cm} (3)

Wherein $EB_w$ is the water resources ecological surplus and deficit index (hm$^2$). It have exceeded the capacity of the ecological environment system and are not conducive to sustainable development.
3.4. Ten-thousand-yuan GDP water footprint

Ten-thousand-yuan GDP water resources ecological footprint (B) is used for measuring water use efficiency in the development of a region. The smaller the ecological footprint of Ten-thousand-yuan GDP, the greater the efficiency, which is not conducive to the sustainable development of the regional economy [7].

\[
B = \frac{\text{EF}_w}{\text{GDP}}
\]  

(4)

3.5. Data Sources

The statistical data used in this paper are mainly based on the 2006-2017 Shaanxi Statistical Yearbook [18] and the Shaanxi Provincial Water Resources Bulletin published by the Shaanxi Provincial Department of Water Resources.

4. Results and analysis

4.1. Determination of main parameters

Referring to the relevant research [14], the main parameter values in the model are determined by calculation, as shown in Table 1.

| Main parameter                                | Parameter value          |
|-----------------------------------------------|--------------------------|
| Water resources global balance factor         | 5.19                     |
| Regional average multi-year production capacity | 2.98×10^4 (m³ km⁻²)     |
| Global average production capacity of water resources | 31.4×10^4 (m³ km⁻²) |
| Production factor of regional water resources | 0.095                    |

4.2. Water resources ecological footprint and ecological carrying capacity

As shown in Figure 1, the per capita production water footprint of Yan'an in 2006-2017 showed a trend of rising first and then stabilizing. The per capita domestic water consumption and per capita ecological water consumption increased slightly each year. Through calculation, the per capita ecological footprint of each account in Yan'an from 2006 to 2017 is shown in Fig. 1. The proportion of production water is the largest, with a ratio as high as 94.4%. In production water, agricultural irrigation water consumption accounted for the dominant factor from 2006 to 2008, but the overall agricultural water consumption showed a downward trend, from 0.0553 hm² per capita in 2006 to 0.0424 hm² per capita in 2017 by 23.3%. In 2009-2017, the industrial water consumption exceeded the agricultural irrigation water consumption, becoming the dominant factor in production water consumption. At the same time, the industrial water consumption showed an increasing trend, from 0.0484 hm² per capita in 2006 to 0.0536 hm² per capita in 2017 by 10.6%.

Fig. 1 Trend of per capita ecological footprint of each account in Yanan City from 2006 to 2017
As shown in Figure 2, the ecological footprint of per capita water resources in Yan'an from 2006 to 2017 generally rises in a fluctuating way due to economic and social development, but the degree of change is not obvious. The per capita ecological carrying capacity and ecological deficit are fluctuating, and the two trends of change are reversed. The per capita ecological carrying capacity fluctuated greatly over the years, and the overall trend is steady with a peak of 0.0562 hm² per capita in 2013 and the minimum of 0.0209 hm² per capita in 2015. The difference between them was 0.0353 hm² per capita. It can be seen from the calculation that the water supply in Yan'an is in an ecological deficit state. The maximum value was 0.1629 hm² per capita in 2015, and the minimum value was 0.1189 hm² per capita in 2013, with a difference of 0.044 hm² per capita. The annual average water resource deficit was 0.1477 hm² per capita.

![Figure 2](image-url)

**Fig. 2 Changes of per capita ecological footprint, ecological carrying capacity and ecological deficit in Yanan city from 2006 to 2017**

4.3. Ten-thousand-yuan GDP water footprint results

It can be seen from Figure 3 that the ecological footprint of ten-thousand-yuan GDP water resources in Yan'an from 2006 to 2017 was generally decreasing, from 0.0674 hm² / 10000 yuan in 2006 to 0.0336 hm² / 10000 yuan in 2017 with the decline rate of 50.13%. The decline in the ecological footprint of ten-thousand-yuan of GDP indicates that in the process of economic development of Yan'an, water resources have not been excessively consumed but the utilization efficiency has been effectively improved. It can be calculated that the rate of decline in GDP per 10000 yuan in Yan'an is significantly higher than the increase in the per capita water resources ecological footprint, indicating that Yan'an has achieved effective results in energy conservation and emission reduction.

![Figure 3](image-url)

**Fig. 3 Trend of ecological footprint of ten-thousand-yuan GDP water resources in Yanan city from 2006 to 2017**
5. Conclusions and recommendations

(1) From 2006 to 2017, the per capita water resources ecological footprint in Yan'an has always been greater than the ecological carrying capacity of water resources. The supply of water resources is in an ecological deficit state. It can be seen that the utilization of water resources in Yan'an is in an imbalanced state of supply and demand. It is difficult to maintain the needs of current social and economic development.

(2) The proportion of each account of water resources footprint reflects the changes in the industrial structure system of Yan'an. Among all the accounts of the ecological footprint of water resources, the production account accounts for the largest proportion, and the industrial water consumption exceeds the amount of agricultural irrigation water in 2009. It becoming the dominant factor of production water and accounting for the largest proportion and showing an increasing trend year by year, which indicates the Yan'an's transformation from agriculture to industry.

(3) The overall ecological footprint of ten-thousand-yuan GDP in Yan'an from 2006 to 2017 showed a downward trend, indicating that the utilization rate of water resources in Yan'an has been increasing, as well as the capacity of ecosystem development. This is closely related to the implementation of Yan'an Municipal Government's policy on water ecological civilization city construction and the improvement of residents' morality.

In the context of the new era, Yan'an should choose a comprehensive development strategy that does not limit economic development and can use water resources in a rational way in order to achieve sustainable and healthy development. On the one hand, they should promote water-saving agriculture and low-water consumption industries, adjust the industrial structure, strengthen the rational development of animal husbandry and forestry, improve the development and utilization of water resources and utilization efficiency, and actively develop green energy, and promote regional industrial transformation in combination with regional development advantages. On the other hand, they should formulate and improve relevant water use policies to rationally allocate water resources which can promote sustainable development of the social and economic environment in Yan'an.

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