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The Spatial and Temporal Evolution of Water Resources Ecological Footprint and Ecological Carrying Capacity in the Shiyang River Basin, China

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Abstract: Water resource is the basic resource of Shiyang River basin, and also the most critical resource for the development and progress of Shiyang River Basin. The study of ecological carrying capacity through water ecological footprint is conducive to solving the contradiction between domestic water and ecological water, realizing the efficient utilization and sustainable development of water resources, and has a far-reaching impact on the overall planning of regional water resources and the harmonious development of economy, society and nature. This study used a model to calculate the ecological footprint and ecological carrying capacity of water resources in the Shiyang River Basin over the past 10 years and discussed the coupling relationship between them using a correlation analysis method. The results showed that the ecological footprint of water resources in the Shiyang River Basin was positively correlated with water consumption and there was no obvious linear relationship between the ecological footprint of water resources and ecological carrying capacity. The variation in the ecological footprint of water resources in the Basin with the total population was small and the variation in the ecological footprint of water resources was positively correlated with the variation in water consumption. The ecological carrying capacity of water resources was directly proportional to the total population and annual runoff. The results are of great significance for the optimisation of water resources in the Shiyang River Basin and provide decision support for water resource management and planning in the basin.

1. Introduction

Water resources are irreplaceable resources for economic development and social progress. With the development of society and economy, the soaring demand for industrial and agricultural water has caused the contradiction between human and water to become more prominent, which has seriously threatened human survival. Climate change and unequal regional distribution of water resources seriously limit the sustainable development of water-poor areas. The Shiyang River Basin is an important ecological protection area in the Hexi Corridor of Gansu Province and has an extremely fragile environment. The recharge of the drainage system depends mainly on the meltwater of the Qilian Mountains. The upper reaches of the basin are mainly woodlands and grasslands and animal husbandry is relatively developed. The middle and lower reaches are mainly cultivated and bare land. The regional water supply mainly depends on the water system of the Shiyang River Basin. Therefore, the runoff of the Shiyang River Basin determines the survival and economic development of its residents. Water resources have become a constraint on agricultural development of the basin and how to measure water resources reasonably has become a problem that requires a solution. At present, ecological carrying capacity and ecological footprint are widely used in water resources measurement but there have been few studies on water resources in inland river basins in dry-early regions[1]. Based on the methods of ecological footprint and ecological carrying capacity, this paper analyses the water resources in the Shiyang River basin, determines the situation and linkages between water resources and ecology, and proposes reasonable opinions and suggestions on how to effectively utilise water resources in the future, providing a reference for the planning and management of water resources in an inland river basin in a dry-early region[2].

2. Research on the District's General Situation

The Shiyang River Basin lies in the east of the Hexi Corridor, with the Qilian Mountains in the south. The administrative divisions of the river basin include most of Wuwei City, most of Jinchang City, and part of Sunan Yugur Autonomous County. It is lied in the intersection and transition zone of three plateaues, spanning Qilian Mountains, Hexi Corridor, Beishan and Alaxia Plateau, with an elevation of 1182-5202mm and a drainage area of 4.27×10^4 km^2(Figure 1). The whole Shiyang River basin mainly includes eight main tributaries of Dajing River.The basin has abundant sunshine, and large temperature differences. The terrain is generally high in the southwest and low in the northeast. The upper reaches of the basin are dominated by woodlands and grasslands and there are many grazing areas with low vegetation coverage. Mainly in the middle and lower reaches by cultivated land and bare land, and land desertification is severe in the middle and lower reaches. From east to west, the Shiyang River basin is mainly composed of several rivers originating in the Qilian Mountains. River recharge mainly comes from mountain precipitation and alpine snow and ice meltwater, with an average precipitation of 450 mm and runoff area of 1.1×10^4 km^2. One-third of the precipitation is converted into surface runoff.

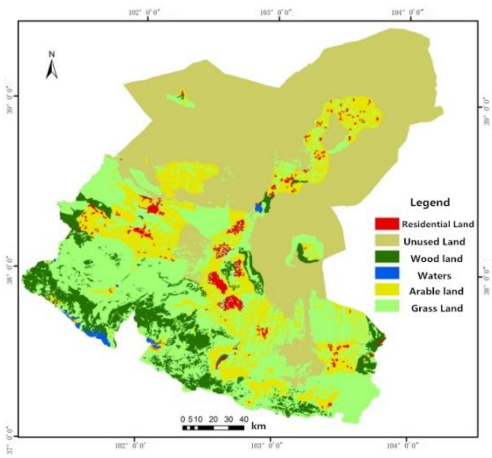

Figure 1: Study area of the Shiyang River Basin

3. Research Method

The data in this study are mainly from the water resources bulletin of Gansu Province and the county statistical yearbook from 2008 to 2018.

3.1. Ecological Footprint Model of Water Resources

The ecological footprint refers to the area with ecological productivity (including land and water areas) occupied by human consumption of natural resources or waste[3]. Including ecological service functions with ecological impact[4].

According to the definition, as follows:

$$EF_w = N \times \mathrm{ef}_w \tag{1}$$

where EF_W is the ecological footprint of water resources (hm^2), N is the population (10000), and ef_W is the per capita water resources ecological footprint ($hm^2.cap^{-1}$).

3.2. Water Resources Ecological Carrying Capacity Model

The ecological carrying capacity mainly refers to the maximum limit that a certain natural resource in the region can bear or the maximum pressure that the region can bear[5]. The ecological carrying capacity of water resources is based on the carrying capacity of the total water, that is, the annual runoff in the basin[5].

According to the definition, as follows:

$$EC_w = N \times \mathrm{ec}_w \tag{2}$$

where EC_W is the ecological carrying capacity of water resources (hm^2), N is the population (10000), and ec_w is the per capita water resources ecological carrying capacity (hm^2cap^{-1}).

3.3. Ecological Carrying Capacity and its Correlation with Ecological Footprint

Based on linear algebraic vector space and using linear correlation, the linear regression equation of the ecological carrying capacity and its ecological footprint correlation is defined as follows[6]:

$$\hat{a} = \bar{y} - \hat{b}\bar{x} \tag{3}$$

$$\hat{b} = \frac{\sum_{i=1}^{n} x_i y_j - n\bar{x}\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2} \tag{4}$$

where x is the ecological carrying capacity and y is the ecological footprint.

4. Result Analysis

4.1. Ecological Footprint of Water Resources in Shiyang River Basin

According to the formula for the ecological footprint of water resources (Table 1, Figure 2, and Figure 3), the ecological footprint of water resources from 2008 to 2018 can be obtained. The ecological footprint of water resources is positively correlated with water consumption. From 2008 to 2018, the population showed a decreasing pattern but the change was small, with a decrease of 51400 (2%). Generally, water consumption showed a decreasing trend, with a relatively large range of change, decreasing to 960 million m^3 in 2018. Water consumption decreased sharply in 2009 and the ecological footprint increased slightly in 2017. The annual water consumption in 2009 was the same as that in 2017 and the ecological footprint of water resources in 2009 was the same as that in 2017, which may be related to the population. Changes in the water ecological footprint are closely related to the total population and water consumption. The amount of water consumed determines the development of the region and its future economic level.

Table 1: Ecological footprint of water resources in Shiyang River Basin (Unit: hm^2)

	Total population (10^4)	Water consumption ($10^8 m^3$)	Ecological footprint of water resources
2008	224.87	30.8	6926.00
2009	224.87	22.6	5082.06
2010	224.87	27.9	6301.77
2011	223.98	26.1	5845.88
2012	223.76	25.8	5773.01
2013	222.68	25.1	5589.27
2014	222.53	24.7	5496.49
2015	222.12	23.5	5219.82
2016	221.98	22.2	4931.06
2017	221.70	22.6	5019.29
2018	219.73	21.2	4636.30

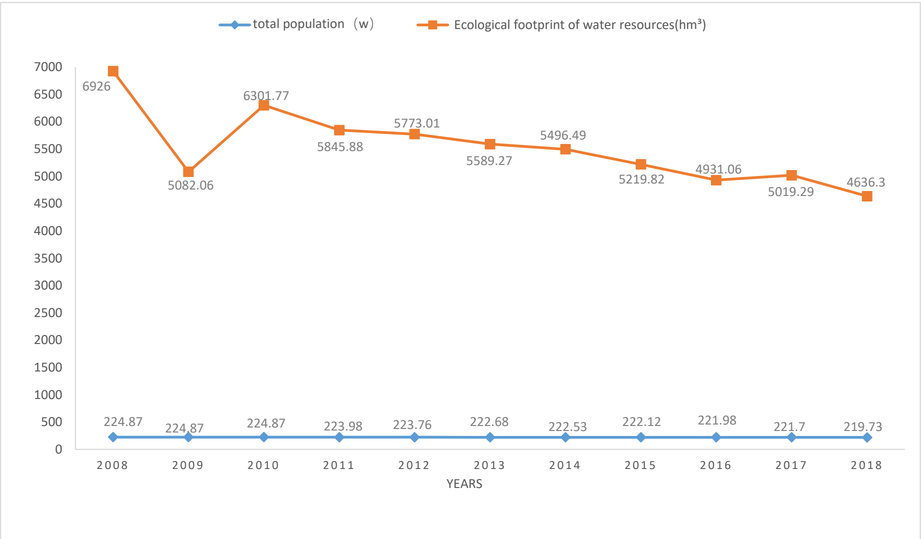

Figure 2: Ecological footprint of water resources and total population in Shiyang River Basin.

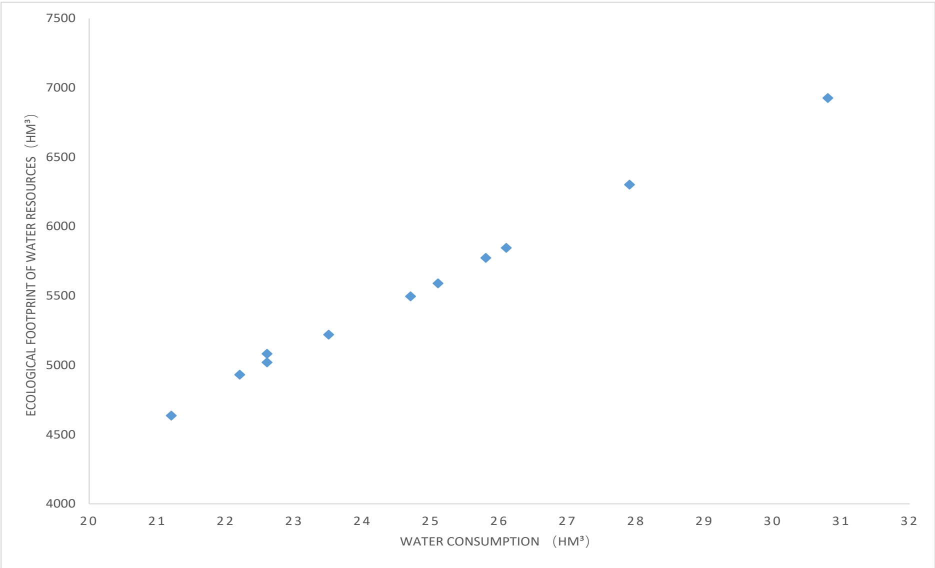

Figure 3: Ecological footprint of water resources and water consumption in Shiyang River Basin.

4.2. Ecological Carrying Capacity of Water Resources in Shiyang River Basin

According to the formula for the ecological footprint of water resources (Table 2, Figure 4 and Figure 5), under the condition that the population base has remained relatively unchanged over the last 10 years from 2008 to 2018, and annual runoff showed an increasing state and the change in the ecological carrying capacity of water resources depended on the annual runoff. There was an obvious coupling relationship between the annual runoff and ecological carrying capacity of water resources in the Shiyang River region. The ecological carrying capacity of water resources peaked in 2012 and the corresponding annual runoff peaked in 2012, with the same annual runoff in 2010 and 2016. The ecological carrying capacity in 2016 was relatively smaller than that in 2010 but the population in 2010 was larger than that in 2016. Therefore, the ecological carrying capacity of water resources was directly proportional to the total population and annual runoff: the larger the ecological carrying capacity, the more resources people can use and the more sustainable the environment will.

Table 2: Ecological carrying capacity of water resources in Shiyang River Basin (Unit: hm^2)

	Total population (10^4)	Annual runoff ($10^8 m^3$)	Ecological carrying capacity of water resources
2008	224.87	2.83	636.38
2009	224.87	2.82	634.13
2010	224.87	3.50	790.77
2011	223.98	3.12	698.81
2012	223.76	3.57	798.82
2013	222.68	2.51	558.92
2014	222.53	3.06	680.94
2015	222.12	2.94	653.03
2016	221.98	3.50	777.42
2017	221.70	3.21	711.657
2018	219.73	3.25	714.12

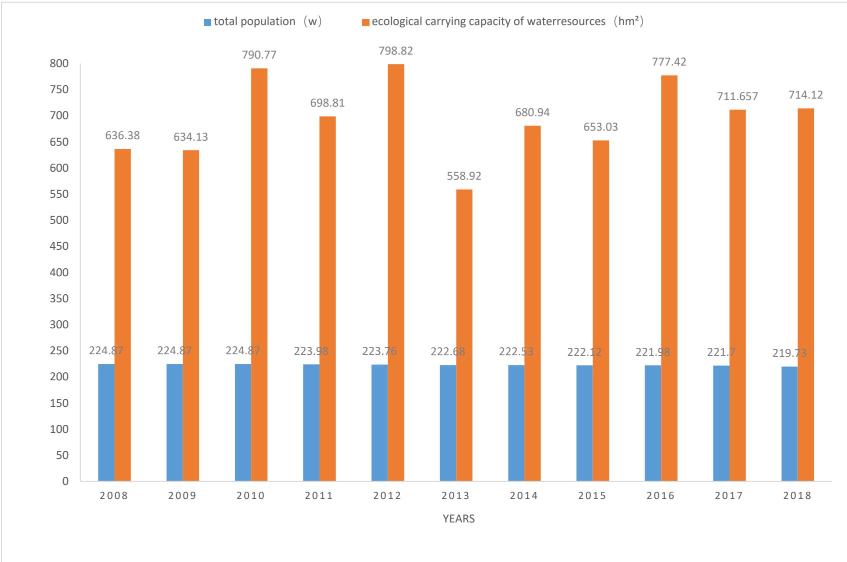

Figure 4: Ecological carrying capacity of water resources and total population in the Shiyang River Basin.

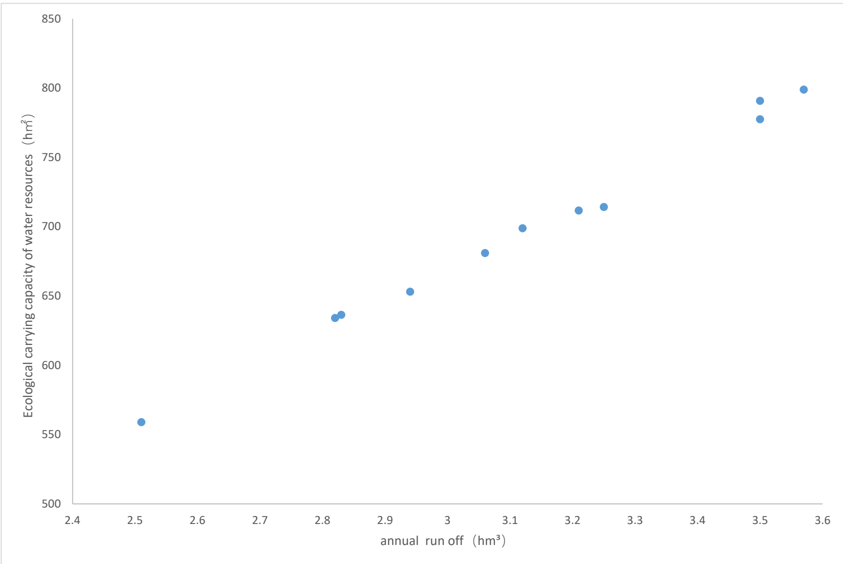

Figure 5: Ecological carrying capacity of water resources and annual runoff Shiyang River Basin.

4.3. Correlation Analysis of Ecological Footprint and Ecological Carrying Capacity of Water Resources in Shiyang River Basin

The r^2 and its linear regression equation were obtained. In the linear equation, the coefficient of x was -0.0221 and r^2 was 0.0436. The linear diagram shows that the ecological footprint of water resources and its ecological carrying capacity in the Shiyang River Basin were negatively correlated and the correlation was small (Table 3, Figure 6). There was no obvious linear relationship. The governance of water resources in the basin was not related to the development of water resources in the basin but was related to the amount of water, with the reduction in water volume being inseparable from people's water consumption. Therefore, the destruction of water resources in the basin is related to the ecological footprint of local water resources. The governance of water resources in the Shiyang River Basin should consider the overall situation to find an exclusive solution.

Table 3: Water resources ecological footprint data and ecological carrying capacity in Shiyang River Basin.

	Ecological footprint of water resources	Ecological carrying capacity of water resources
2008	6925.996	636.38
2009	6453.769	634.13
2010	6301.773	790.77
2011	5845.878	698.81
2012	5773.008	798.82
2013	5589.268	558.92
2014	5496.491	680.94
2015	5219.82	653.03
2016	4931.064	777.42
2017	5019.288	711.657
2018	4636.303	714.12

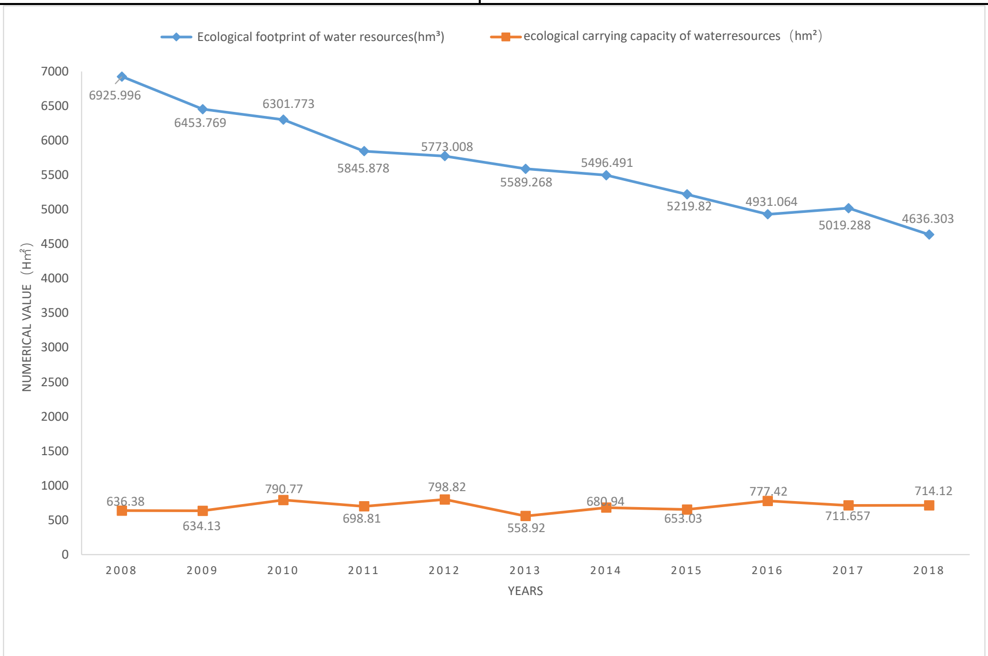

Figure 6: Water resources ecological footprint data and ecological carrying capacity in Shiyang River Basin.

5. Discussion

The ecological footprint was calculated based on the total water consumption. As the water consumption data was not subdivided, the calculation result was macro level. With this method, it is difficult to accurately analyse which regions consume more water and the analysis direction will be biased. Similarly, the ecological carrying capacity was only calculated from a single annual runoff, which causes bias in the calculation.

The management of water resources in the Basin should first consider the water volume, whether from the perspective of the ecological footprint or ecological carrying capacity. To improve the ecological plight of the Shiyang River Basin, we need to achieve both open-source and throttling from the water volume to improve the water resources in the basin. We can consider the allocation of water resources in this region, realise inter-basin water transfer, reduce water use, increase water recycling, and realise the maximum production value. Simultaneously, changing the single production structure, promoting industrial optimisation and upgrading, and alleviating local economic development can alleviate the use of local water resources so that water resources can become a non-limiting factor in the Shiyang River Basin.

But on the other hand, with the growth of population, industrial, agricultural and domestic water consumption surge, water resources tension, water environment deterioration, a serious threat to the production and life of people in this area. Global climate change intensifies the instability of water supply and the unsustainability of economic production in water-scarce areas. Therefore, in the context of global water shortage, the concept of sustainable utilization of water resources comes into being, and the concept of water carrying capacity is also proposed, which is crucial to sustainable development. The carrying capacity of water resources must consider factors such as economic and technological level, social production conditions, population and regional development ability. The study of water ecological footprint on the carrying capacity of water resources is very comprehensive, in line with the concept of sustainable development. It is very important to study the carrying capacity of water resources in water-scarce areas.

With the increase of inter-basin water transfer and precipitation, the carrying capacity of water resources in Shiyang River Basin increases. But if industry and agriculture continue to use more water, the ecological deficit will become more serious. Rational and efficient utilization of water resources has become an urgent task. The ecological environment problems in arid inland basins are often caused by the lack of unified management of water resources, the blind expansion of cultivated land and the continuous over-exploitation of groundwater. The total amount of water used for agricultural production should be controlled appropriately in Shiyang River basin. In addition, Shiyang River basin, as an important commodity grain base in Gansu Province, has a large amount of virtual water output. The results of water resources carrying capacity show that the development potential of water resources in Shiyang River Basin is low. Therefore, it is necessary to strengthen agricultural water-saving work, promote water-saving technologies such as drip irrigation, self-pressure sprinkler irrigation and low-pressure pipeline water transmission, and improve the utilization rate of irrigation water. We will strengthen the construction of farmland infrastructure, promote dry farming techniques, and improve the efficiency of agricultural water use in river basins. Strengthen the construction of water resources management system, formulate a scientific total water resources control and quota management index system. Strengthen the publicity and education of water saving, popularize the use of water saving appliances, formulate reasonable water saving indicators, so as to make efficient use of limited water resources.

6. Conclusion

Based on the analysis of the spatial and spatial evolution characteristics of the water resources in the Shiyang River Basin, ecological footprint, and ecological bearing capacity of the river in 2018, a correlation conclusion was obtained and the development trend of the ecological footprint and the ecological bearing capacity of the water resources in this watershed was predicted.

The change in the ecological footprint of the river area and water consumption showed an obvious positive correlation. The ecological footprint of water resources decreased with the total population and the increase (decrease) in water consumption changed significantly. There was a clear positive correlation between the change in the ecological footprint of water resources and the change in water consumption. The smaller the ecological footprint value, the smaller the disturbance. The total population and water consumption were within a certain range and the ecological environment was optimal. The minimum value of the ecological footprint was in 2018 and the ecology was better this year than in other years. The calculation data of the water resources of the watershed showed that the ecological bearing capacity was related to the population and annual runoff in the basin. The ecological carrying capacity of the basin peaked in 2012, when annual water resources were more abundant and the annual runoff also peaked. This verified that the greater the ecological carrying capacity of water resources, the richer the regional water resources.

There was a significant negative correlation between the ecological footprint of the water resources in the river and the ecological bearing capacity of the river area, indicating that the ecological footprint of the basin was decreasing and the ecological bearing capacity was increasing, which is conducive to improving the ecological environment. To meet the challenges of development, the river area of stone sheep should continue to reduce water use and restore the ecological environment.

Acknowledgments

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