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Inner Mongolia Water Footprint Account Accounting and Water Resources Evaluation Analysis

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Abstract: *On the basis of expounding the concepts of virtual water and water footprint, and summarizing the calculation method of water footprint based on the virtual water content of products, taking Inner Mongolia Autonomous Region as an example, the water footprint and its related indices (water scarcity degree) of 12 administrative regions from 1995 to 2020 were calculated. , water resources dependence, water resources self-sufficiency rate and water footprint intensity), analyzed the time series of water footprint and water footprint intensity, and further explored the temporal and spatial differences of water footprint in each administrative region through the water footprint pressure index. The results show that, from the time point of view, the water footprint shows an increasing trend, while the overall water footprint intensity shows a downward trend. There are differences in the degree of dependence and the degree of externalization of the water footprint.*

Keywords: *water footprint, water footprint account, water footprint intensity, water resource assessment*

1. Introduction

Water is the foundation of life and the most basic and important natural resource and environmental element. The survival of any animal and plant cannot be separated from water. Not only that, the development of economy and society and the progress of human civilization are also inseparable from water resources, and water resources are also regarded as strategic economic and social resources. Development, efficient utilization, and effective protection of water resources to promote sustainable development of water resources, so as to achieve sustainable use of water resources. According to the characteristics of water resources, water resources can be divided into physical water and virtual water. The concept of virtual water was first proposed by British scholar Allan in 1993. He defined it as "water consumed in the process of producing products or services." Resource[1], it refers to "water contained in the product, and it is water in a virtual sense rather than a real meaning". In 2002, Hoekstra proposed the concept of water footprint based on the concept of virtual water, which is different from the concept of water footprint. The traditional water use indicators based on the production sector, the concept of water footprint is a consumption-based water consumption indicator, which aims to measure the real water consumption in a certain area more comprehensively and accurately, which is an improvement on the previous water resources measurement methods [2] .After the "Water Footprint Evaluation Manual" was released as an international standard manual in 2011, water footprint really attracted the attention of various organizations, and gradually became a research hotspot in the field of water resources management [3].

Falkenmark proposed the concept of green water and blue water in 1993 and 1995 respectively [4], Hoekstra proposed the concept of grey water [5], Hoekstra et al. took the lead in dividing the water footprint into blue water footprint, green water footprint and grey water footprint. This classification changes the phenomenon that traditional water resources accounting only pays more attention to blue water calculation, and links the production, consumption and pollution of water resources together to build a more comprehensive system. At present, the research on grey water footprint has made some progress. Foreign countries mainly focus on the calculation of grey water footprint of specific products, regions or enterprises. The research on grey water footprint in China is still in the preliminary stage, and there are few studies on the calculation of grey water footprint alone. With the continuous development of scholars' research on regional water footprint, domestic scholars in China have divided the water footprint into agricultural and animal products water footprint, industrial product water footprint, and living ecological water footprint by establishing water footprint accounts [6-7]. this classification is an improvement on previous methods and provides guidance for water resources planning [8].

China's Inner Mongolia Autonomous Region has a vast territory. Due to the differences in geographical location and climatic conditions, there are different water resources problems among different alliance cities. Considering the actual situation of Inner Mongolia Autonomous Region and the availability of data, this study will divide the water footprint into agricultural water footprint, industrial water footprint, living ecological water footprint and water pollution footprint according to the water footprint account. In the literature on water resources utilization research, most of them directly use water footprint to represent the level of regional water resources utilization, while there are few comprehensive studies based on the calculation results of water footprint and other indicators; The research focuses on the status quo year analysis and ignores the spatiotemporal dynamic analysis. In view of this, this study firstly conducted a spatiotemporal analysis of the water footprint of Inner Mongolia Autonomous Region, and then integrated the water footprint calculation results to construct a comprehensive evaluation index system, which is helpful to understand the spatial distribution and development law of water scarcity in Inner Mongolia, and is more conducive to accurate understanding in the future. The essentials of green development and sustainable development provide a certain theoretical basis for the research on medium and long-term utilization planning of water resources in the study area and optimal allocation of water resources.

2. Research methods and data sources

2.1. Introduction to the study area

The Inner Mongolia Autonomous Region is located in the northern frontier of China, extending diagonally from northeast to southwest, spanning a wide range of latitudes and longitudes, with a straight line distance of more than 2,400 kilometers, in a narrow and long shape. The total land area is 1.183 million square kilometers, accounting for 12.3% of the country's total area, ranking third among all provinces, municipalities and autonomous regions in the country. In the natural division of the world, collectively referred to as the Inner Mongolia Plateau(Figure 1), it is the second largest plateau among the four major plateaus in China. In terms of internal structure, there are obvious differences. Among them, high plains account for about 53.4% of the total area of the region, mountains account for 20.9%, hills account for 16.4%, plains and beaches account for 8.5%, rivers, lakes, reservoirs and other waters The area accounts for 0.8%. There are thousands of rivers and nearly 1,000 lakes in the Inner Mongolia Autonomous Region. There are 107 rivers with a drainage area of more than 1,000 square kilometers. The hydrogeological structure is complex and diverse, and various types of groundwater are distributed. There are regular changes from east to west or from southeast to northwest. Precipitation is small and unevenly distributed in time and space, generally between 50 and 450 mm; the water and heat are in the same period, but the water and heat match is not balanced; the ecological environment conditions in most regions are fragile, and the ecological environment is extremely sensitive to external disturbances and is extremely vulnerable to Impact of climate change and human economic activity.

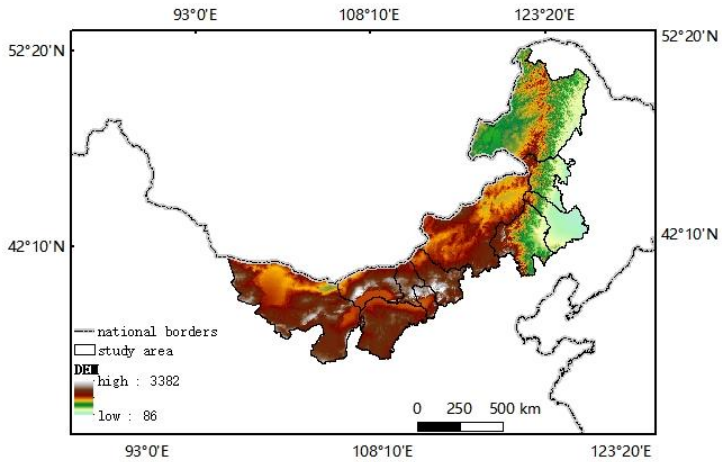

Figure 1: Elevation map of Inner Mongolia Autonomous Region

2.2. Research methods

According to the composition and classification of water footprint accounts, and considering the actual situation of Inner Mongolia Autonomous Region and the availability of data, this paper divides the water footprint of Inner Mongolia Autonomous Region into: agricultural water footprint, industrial water footprint, living water footprint, ecological water footprint, and water pollution. 5 categories of footprints. The water footprint describes the total amount of water resources for all services and products consumed by the population in a region, and the total water footprint is equal to the region's internal water footprint plus the external water footprint.

$$\mathrm{WFP} = \mathrm{AWF} + \mathrm{IWF} + \mathrm{LWF} + \mathrm{EWF} + \mathrm{PWF} \tag{1}$$

where WFP is total water footprint, m^3/a; AWF is agricultural water footprint, m^3/a; IWF is industrial water footprint, m^3/a; LWF is living water footprint, m^3/a; EWF ecological water footprint, m^3/a a; PWF is the water pollution footprint, m^3/a.

The agricultural water footprint is further broken down into the water footprint of crops, livestock products, and fishery products. Quantitative calculation of water resources is carried out for specific crops, livestock products, fishery products, industrial products, etc. under each sub-category. Since these are based on an area's internal water footprint, the final calculation also needs to add a portion of the virtual water imported from the outside. The specific accounting model is:

For the agricultural water footprint, this paper adopts the concept of generalized agriculture, and calculates it from three aspects: crops, livestock products, and fishery products. The formula for calculating the Agricultural Water Footprint AWF is:

$$\mathrm{AWF} = \mathrm{AWF_C} + \mathrm{AWF_L} + \mathrm{AWF_F} \tag{2}$$

In the formula, AWF_C is the water footprint of crops, AWF_L is the water footprint of livestock products, and AWF_F is the water footprint of fishery products.

The formula for calculating crop water footprint AWF_C is:

$$AWF_C = \sum P_i \times VWF_{C_i} \tag{3}$$

In the formula, $P_i$represents the yield of the i crop, and VWF_{C_i} represents the virtual water of the i unit crop product. The formula for calculating the water footprint AWF_L of livestock products is:

$$AWF_L = \sum P_j \times VWF_{L_j} \tag{4}$$

In the formula, P_j represents the output of the j livestock product, VWF_{L_j}, represents the virtual water of the j unit livestock product. The formula for calculating the water footprint of fishery products, AWF_F, is:

$$AWF_F = \sum P_k \times VWF_{Fk} \tag{5}$$

In the formula, P_k represents the output of the k fishery product, VWF_{Fk} represents the virtual water of the k unit fishery product.

Due to the variety of industrial and ecological water use, it is difficult to obtain data. The specific calculation of its water footprint is mainly based on the existing literature and environmental yearbooks, water resources bulletins and industry data to obtain the corresponding water resources consumption. For the industrial water footprint, it is measured from the perspective of the producer, and the industrial water footprint is estimated through the GDP and industrial consumption coefficient.

$$\mathrm{IWF} = \mathrm{WF_1} + \mathrm{VWF_1} - \mathrm{VWF_E} = \mathrm{WF_1} + (\mathrm{IPTV_1} - \mathrm{IPTW_E}) \times \mathrm{WF_T}/\mathrm{GDP} \tag{6}$$

In the formula, IWF represents the industrial water footprint, and WF_1, VWF_1, and VWF_E: represent the industrial water consumption, imported virtual water, and exported virtual water, respectively. WF_T means regional water consumption, $IPTV_1$, $IPTW_E$: respectively import,trade value of exported industrial products.

For the Living Water Footprint (LWF), due to the limitation of data acquisition,this study uses the domestic water consumption of residents to represent it, which refers to the daily water consumption of all urban households, including urban residents and farmer households. and public water supply stations.

Ecological Water Footprint (EWF) refers to the amount of water consumed to maintain the ecological environment, expressed as green space water consumption. Its calculation formula is:

$$\mathrm{EWF} = 0.3 \times \mathrm{GA} = 0.3 \times \mathrm{GA_P} \times \mathrm{AAP} \quad (7)$$

In the formula, EWF is the ecological water footprint, GA is the green space area, GAp is the per capita green space area, and AAP is the average population.

The water pollution footprint (PWF) is determined by the larger value of the ratio between the chemical oxygen demand and ammonia nitrogen emissions and the discharge standards, respectively. Due to limited data acquisition, this paper only considers industrial chemical oxygen demand emissions and ammonia nitrogen emissions, and the calculation formula is:

$$\mathrm{PWF} = \max\left(\mathrm{P_c}/\mathrm{NY_c}, \mathrm{P_n}/\mathrm{NY_n}\right) \quad (8)$$

In the formula, Pc represents the industrial chemical oxygen demand COD discharge, NYc represents the water carrying capacity for COD, P represents the industrial ammonia nitrogen discharge, and NY represents the water carrying capacity for ammonia nitrogen. Both $\mathrm{NY_c}$ and $\mathrm{NY_n}$ adopt the secondary discharge standard in the sewage discharge standard (GB8978-1996), which are: 120mg/L and 25mg/L, respectively.

The water footprint intensity reflects the utilization efficiency of water resources, and is calculated from the ratio of the total water footprint to the gross domestic product (GDP). The formula is:

$$\mathrm{WFI} = \mathrm{WF}/\mathrm{GDP} \quad (9)$$

In the formula, WFI represents the water footprint intensity, WF represents the total urban water footprint, GDP represents the gross urban product, and WFI reflects that the more water footprint consumed per unit of GDP, the lower the water utilization efficiency.

The water resources stress index refers to the ratio of the total urban water footprint to the total water resources, reflecting the intensity of water resources pressure. The formula is:

$$\mathrm{WPI} = \mathrm{WF}/\mathrm{WT} \quad (10)$$

In the formula, WPI is the water stress index, WF is the total water footprint of Inner Mongolia, and WT is the total urban water resources. When WPI<1, it indicates that the city is rich in water resources, which can meet the water demand for production and life, and is in a safe state; when WPI=1, it indicates that the city is in a state of balance between supply and demand; when WPI>1, it indicates that the city has insufficient water resources. And the larger the value, the more prominent the water resources security problem.

2.3. Data Sources

The data come from "Inner Mongolia Statistical Yearbook (1995-2020)", "Inner Mongolia Environmental Statistical Yearbook (1995-2020)" Statistical Yearbook (1995-2020) of all leagues and cities in Inner Mongolia, Bulletin of Water Resources (1995-2020) and National Economy and Social Development Bulletin (1995-2020), etc., some raw data are calculated and processed to obtain indicator data. For individual default data, according to the function type that the existing data of the indicator may belong to, use interpolation method and least square method to perform curve fitting, and select the function expression with the smallest error squared sum as its optimal fitting function, so as to fill in the individual gaps.

3. results and analysis

In order to clarify the water resource consumption, water resource utilization efficiency, and carrying capacity of Inner Mongolia Autonomous Region, this chapter introduces the concept of water footprint account based on the water footprint model. The five major water footprints, total water footprint, water footprint intensity and water stress index of 12 league cities in Inner Mongolia Autonomous Region from 2003 to 2020 were calculated, and the water footprints of 12 league cities in Inner Mongolia Autonomous Region were analyzed.

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3.1. Inner Mongolia Autonomous Region Water Footprint Accounting

3.1.1. Agricultural Water Footprint Measurement

Inner Mongolia is located in the northern frontier of China, with long winters, low precipitation, long distances from east to west, large north-south spans, different terrains, diverse climates, relatively little pollution, sufficient light, and large temperature differences between day and night. In the same period of rain and heat, the population is relatively sparse, and the per capita arable land is more, which provides better conditions for the development of agricultural production. Inner Mongolia's agricultural products can be mainly divided into two categories: grain and cash crops, and there are 11 sub-categories. Grains include rice, wheat, corn, soybeans, and potatoes, and cash crops include cotton, oil crops, sugarcane, sugar beets, tobacco, and fruits. The six major livestock products include pork, beef, mutton, poultry, eggs, and milk. Considering the availability of data, according to relevant statistical yearbooks, in this paper, crops mainly consider wheat, corn, soybeans, potatoes, oil crops, and 5 categories, and livestock products mainly consider beef, pork, mutton, milk, poultry and eggs. 5 species, fishery products mainly consider aquatic products.

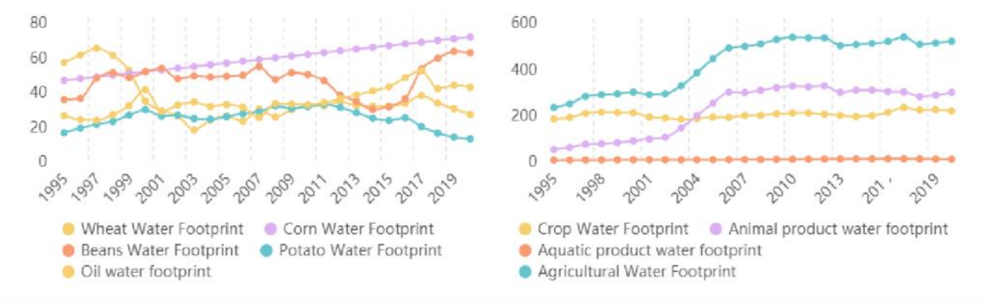

Figure 2: Crop water footprint and agricultural water footprint in Inner Mongolia (100 million m3)

There are as many as 10,266 varieties of crops in 25 categories in Inner Mongolia, among which the grain production is dominated by the four major crops of corn, wheat, soybean and potato, as well as miscellaneous grains and beans such as millet, sorghum, naked oat, millet and mung bean. As shown in the Figure2, as the wheat planting area in Inner Mongolia gradually decreased from 1,016.7 thousand hectares in 1995, by 2020, the wheat planting area in Inner Mongolia was only 478.96 thousand hectares, and the water footprint of wheat decreased year by year. At the same time, the corn sown area has increased from 992.1 thousand hectares in 1995 to 3823.9 in 2020, and the water footprint of corn has increased year by year. The water footprint of beans and oilseeds showed a slow growth trend, and the water footprint of potato showed a trend of increasing first and then decreasing.

3.1.2. Total Water Footprint Accounting of Inner Mongolia

From 2003 to 2020, the agricultural water footprint, industrial water footprint, residential water footprint, ecological water footprint, and water pollution footprint of Inner Mongolia Autonomous Region are added to obtain the total water footprint. The calculation results are shown in Figure 3. According to the analysis in Figure 3, from 2003 to 2020, the total water footprint showed an increasing trend; from 34.597 billion m3 in 2003 to 56.885 billion m3 in 2020, the trail dominated; the change trend of the total water footprint was related to the province's economic and social Development is closely related, and its driving and influencing factors are mainly urban development status, population size and structure, and economic development level. Figure 3 shows the water footprint of each department in Inner Mongolia from 2003 to 2020. It can be seen from Figure 3 that in the total water footprint of the whole region, agricultural water footprint has always dominated, and its annual average is 53.358 billion m3 respectively, indicating that agriculture is the main sector of water resources consumption in Inner Mongolia, and agricultural production brings water resources to the region. Great pressure; the industrial blue water footprint grew slowly before 2013, and showed a downward trend from 2014 to 2018. Before 2003, the industrial production value of the study area increased year by year. In 2013, the study area fully implemented the spirit of the 18th National Congress of the Communist Party of China. Accelerating transformation and upgrading in major development strategies will promote the decline of industrial water footprint to a certain extent; from 2003 to 2020, the domestic water footprint will be 524-927 million m3. In conclusion, the domestic water structure of residents in the study area has not changed significantly in recent years. The significant increase in ecological water consumption is related to the large-scale ecological construction in recent years. Relevant studies also show that the vegetation area in the study area has increased, and vegetation productivity is mainly increased, especially Vegetation productivity in forest and desert ecoregions increased significantly.

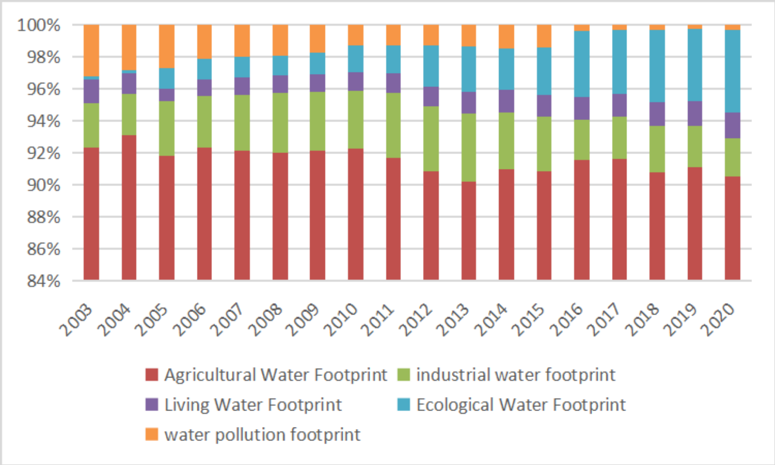

Figure 3: The total water footprint of Inner Mongolia (100 million m3)

3.1.3. Water Footprint Accounting of All Leagues and Cities in Inner Mongolia Autonomous Region

According to the virtual water content per unit product, the water footprint of crops, animal products, fishery products, and agricultural water footprints of 12 league cities in Inner Mongolia Autonomous Region were calculated respectively. As shown in Figure 4, overall, in the past 20 years, the agricultural water footprint has gradually increased first, indicating that the water consumption of crops, livestock products and aquatic products in the leagues and cities of the Inner Mongolia Autonomous Region has remained basically stable.

From Figure 4, it can be seen that the composition of agricultural water footprint in various cities in Inner Mongolia fluctuates, and there are large differences among prefecture-level cities. Among them, Wuhai and Alxa are the lowest, which is related to the limited area of local arable land and agricultural development. The rapid growth of the agricultural blue water footprint in 2019 was influenced by the development of local eco-tourism agriculture.

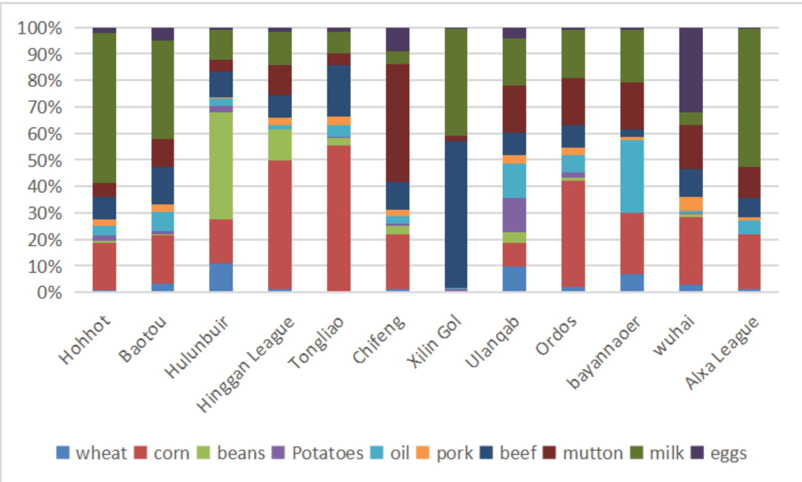

Figure 4: The composition of agricultural water footprint in various cities in Inner Mongolia

3.2. Analysis of Intensity and Pressure Index of Water Resources in Inner Mongolia Autonomous Region

WFI reflects that the more water footprint consumed per unit of GDP, the lower the water utilization efficiency. According to formulas 8 and 9 (Figure 5), during the 18-year period from 2003 to 2020, the water footprint intensity of the 12 league cities in the Inner Mongolia Autonomous Region was 0.06m3. In the 18 years from 2003 to 2020, the water footprint intensity of the 12 league cities in the Inner

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Mongolia Autonomous Region showed a significant downward trend as a whole (Figure 5), with a decline rate of more than 66.7%, indicating that the water resources utilization efficiency of the Inner Mongolia Autonomous Region has been significantly improved. This is mainly constrained by the city's total water footprint and economic scale growth. It can be seen that the population and the level of urban economic development have become the main factors affecting the intensity of the water footprint.

During the 18-year period from 2003 to 2020, the water stress index of 12 league cities in Inner Mongolia Autonomous Region fluctuated and slightly increased during the 18-year period from 2003 to 2020. The average water resource stress index of the 12 league cities during the 18-year period was 1.22. , greater than 1, indicating that the overall water resources security problems are more prominent, the water resources security is seriously threatened, and the water resources security problems are more prominent.

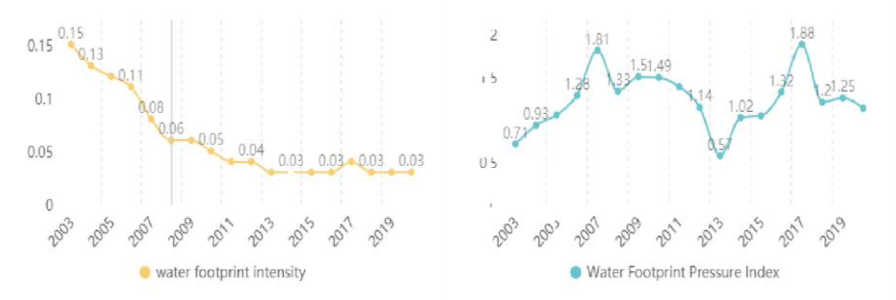

Figure 5: Water resources intensity and water stress index in Inner Mongolia Autonomous Region

4. Conclusions

UIn order to clarify the water resource consumption, water resource utilization efficiency, and carrying capacity of Inner Mongolia Autonomous Region, this chapter introduces the concept of water footprint account based on the water footprint model. The five major water footprints, total water footprint, water footprint intensity and water stress index of 12 league cities in Inner Mongolia Autonomous Region from 2003 to 2020 were calculated, and the water footprints of 12 league cities in Inner Mongolia Autonomous Region were analyzed. Its main findings are as follows:

(1) During the 18 years from 2003 to 2020, the agricultural water footprint showed a chronological evolution trend that first gradually increased and then decreased, and was generally flat. The water footprint of crops, livestock products and fishery products in Inner Mongolia Autonomous Region shows a gradual upward trend, the industrial water footprint fluctuates and gradually declines, and the life and ecological water footprint shows a small fluctuation and rise. The temporal evolution trend of fluctuation and gradual decline.

(2) The calculation of the total water footprint shows that among the five major water footprints, the agricultural water footprint is the largest, followed by the industrial water footprint, the living water footprint, and the water pollution footprint, and the smallest is the ecological water footprint. It can be seen that the focus should be on controlling the agricultural water footprint and the industrial water footprint.

(3) The overall footprint intensity of the Inner Mongolia Autonomous Region shows an obvious downward trend, showing a state of high in the middle and low in the east and west. It can be seen that population and the level of urban economic development are the main factors affecting the intensity of water footprint. The average water stress index of Inner Mongolia Autonomous Region is greater than 1, indicating that water resources are lacking and water resources security problems are more prominent.

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