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Assessing the crop production water footprint in Shandong Province of China

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Abstract. Water scarcity is the major limiting factor to crop production in arid and semi-arid regions. The crop production water footprint (CPWF) and its influence factors of Shandong province during 1996-2015 was calculated and revealed in current paper. The results showed that the annual CPWF of the province was 173.1 G m^3, blue, green and grey water footprint accounted for 12.7%, 64.6% and 22.7% respectively. The water footprint of grain and fruit crops accounted for more than 80% of the total water footprint. The two decided the changes in the water footprint of the study area. The CPWF intensity of the province was 2329.2 mm and showed a decreasing trend over time. The planting structure and the degree of regional economic development can directly affect the crop sowing water footprint of regional crops, in which the control of the proportion of high water consumption crops and the irrigation rate of cultivated land is an effective means for its near regulation. The results of this study can provide reference for regional agricultural water resources management.

1. Introduction

Quantifying the demand of regional crops for water resources can provide a basic for the efficient utilization of water resources in agricultural production, and the water footprint provides an effective tool for this purpose [1]. The water footprint of crops can be divided into blue water footprint, green water footprint and grey water footprint [1]. Blue water and green water footprint are used for the consumption of crop growth for irrigation water and effective precipitation, and the pollutant produced by the grey water footprint [2] of fresh water consumed by the environmental water quality standard. Scholars have quantified and analyzed crop water footprints at different regional scales, including farmland [3], irrigation area [4], administrative region [5], river basin [6], nation [7] and global [8]. Due to the typical conditions of population, agricultural production and water resources, the water footprint of crops in China has been widely reported. Cao et al. [9] used water footprint tools and from the perspective of blue and green water resources to analyse and evaluate the water consumption of grain production in China irrigation area, and the [10] on the regional blue water and the generalized water resources pressure were evaluated. In addition, the water footprint of agricultural production in typical irrigation areas is also concerned, such as Sun et al. [11] and Cao et al.[12] studied the water footprint of wheat and other crops in Hetao irrigation district, and Xin [13] observed the water footprint of rice in the irrigated area of Jiangsu Province. The current research has made significant progress in quantifying the relationship between crop growth and water resources utilization at different regional scales [14-16]. However, the present researches cannot fully identify the real demand of the regional crop sowing to the water resources. Based on the water footprint theory and method, the water footprints of crop water footprints in Shandong province of China were calculated, and temporal changes of d crop production water footprints were analyzed and the influencing factors were explored. In order to provide a reference for the formulation of relevant strategies for the efficient utilization of agricultural water resources, we will provide the overall information on the relationship between crops and water resources.

2. Methods and materials

2.1. Crop production water footprint (CPWF)

Regional $CPWF$ is calculated as the sum of water footprints for all types of crop as follow:

$$CPWF = \sum_{i=1}^{n} CWF_i \quad (1)$$

$$CPWFI = \frac{\sum_{i=1}^{n} CWF_i}{A} \quad (2)$$

where, n is the number of crop category and CWF_i the WF of the i^{th} crop, in m^3. $WFCPI$ is crop production water footprint intensity in mm. A is the total arable land in ha. Agricultural crops including rice, wheat, maize, beans, tubers, cotton, oil-bearing crops, sugar crops, fiber crops, tobacco and tea in Shandong. CWF is the sum of the blue, green and grey WFs for each kind of crop:

$$CWF = CWF_{blue} + CWF_{green} + CWF_{grey} \quad (3)$$

The sum of CWF_{blue} and CWF_{green} is equal to the crop actual evapotranspiration (ET_c) which can be calculated based on the reference evapotranspiration (ET_0) using the Penman–Monteith (PM) equation:

$$ET_c = K_c \times ET_0 \quad (4)$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \times \frac{900}{T+273} \times u_2 \times (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (5)$$

where K_c is the crop coefficient; Δ the slope of the vapor pressure curve, kPa°C^{-1}; R_n the net radiation, MJ m^{-2} d^{-1}; G is the soil heat flux density, MJ m^{-2} d^{-1}; γ is the psychrometric constant, kPa°C^{-1}; T is the average air temperature, °C; u_2 is the wind speed measured at 2 m height, m/s^{-1}; e_s is the saturation vapor pressure, kPa; and e_a is the actual vapor pressure, kPa. The CWF_{grey} was estimated as follow:

$$CWF_{grey} = (\alpha \times AR)/(c_{max} - c_{min}) \quad (6)$$

where α is the leaching-runoff fraction; AR is the rate of chemical application to the field per hectare, kg/ha; c_{max} is the maximum acceptable concentration and c_{min} is the concentration in natural water.

2.2. Influencing factors analysis

Path analysis is used to analyze the driving factors of crop water footprint changes in Shandong province. Through the decomposition of the direct correlation between the independent variable and the dependent variable, the method studies the direct and indirect importance of the independent variable to the dependent variable. The correlation coefficient is decomposed into direct path coefficient and indirect path coefficient [17]. The potential factors selected in this paper include precipitation (P), population density (PD), per capita GDP (PCG), per capita net income (PCNI), fertilizer application per arable land (FA), grain crop yield (GCY), irrigation water use coefficient (IWUC), plant ratio of high water consumption crop (PRH), agricultural water ratio in total water use (AWR) and irrigation rate of cultivated land (IRC). The grain crops are secreted as the high water consumption crops and the total sown area of the crops, and the ratio of the cultivated land to the effective irrigation area and the area of the cultivated land.

2.3. Data resources

The study period of this paper is 1996-2015. The meteorological data for crop water footprint calculation came from 91 meteorological stations located in the province. The parameters included precipitation, monthly mean temperature, wind speed, relative humidity, and sunshine hours were downloaded from China Meteorological Data Network (http://data.cma.cn); crop sown area, cultivated area, effective irrigation in each year. Area, crop yield, fertilizer application, rural per capita net income, year-end population and per capita GDP came from Shandong statistical yearbook 1997-2016.

3. Results and discussions

3.1. CPWF of Shandong province

In 1996-2015, the annual average value of CPWF in Shandong was 173.1 G m^3, of which blue water, green water and grey water footprint were 23.3, 111.1 and 38.0 G m^3 respectively. The values of blue water, green water and grey water footprints are calculated,and shown in Figure 1.

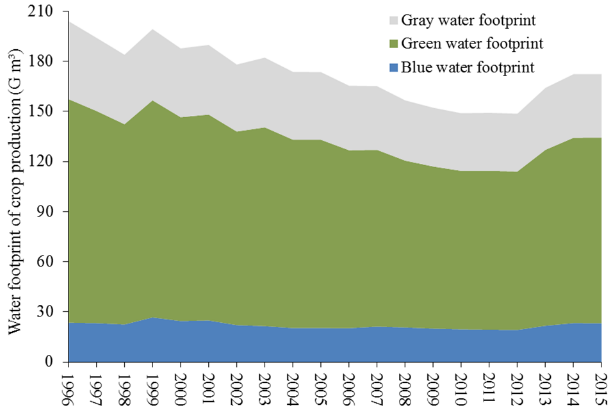

Fig. 1 Crop production water footprint (CPWF) of Shandong during1996-2015

Figure 1 shows that the blue water footprint is basically stable and fluctuates very little. The trend of green and grey water footprint is basically the same, which is first to decrease and then to be stable. The largest blue water footprint appeared in 1999 was 26.7 G m^3, and 19.2 G m^3 larger than the minimum year; the green water footprint was changed between 94.1~133.9 G m^3; the maximum value of the ash water footprint was 46.7 G m^3, appearing in 1996, the minimum value of 34.5 G m^3, appearing in 2010. In general, the crop sowing water footprint in Shandong province showed a trend of first descending and then stable, the difference between the maximum and the minimum was 55.5 G m^3, and the fluctuation was great. In order to better study the change and composition of the crop sowing water footprint in Shandong Province, the proportion of water footprint density and blue, green and gray water footprint of agricultural production in Shandong province for 1996-2015 years was calculated, and the figure 2 was drawn based on the above data.

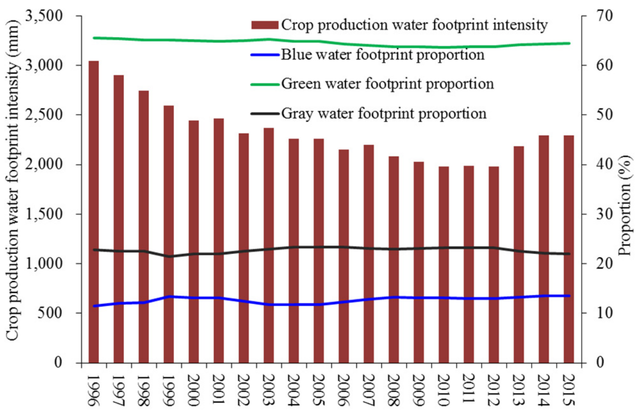

Fig. 2 Water footprint density and composition of 1996-2015 in Shandong

As shown in Figure 2, the annual average value of water footprint density in agricultural production is 2329.2 mm, and the annual average value of blue, green and grey water footprint is 12.7%, 64.6% and 22.7% respectively. From 1996 to 2012, the crop water footprint density declined, and the proportion of blue, green and gray water remained basically unchanged. In 2003, the crop water footprint density dropped suddenly, the proportion of blue water decreased, the proportion of green water rose, and the proportion of green water increased, because of the increase of cultivated land area and the decrease of the total water footprint of the crops in Shandong province. The proportion of water remains unchanged. From 2012 to 2015, the density of water footprint of crops raised slowly, the proportion of blue water rose slightly, the proportion of green water decreased slightly, and the proportion of grey water continued to remain unchanged. From 2008 to 2011, the water footprint density of crops tended to be stable, and the proportion of blue, green and gray water remained stable.

3.2. Composition of crop production water footprint

The crops planted in Shandong include rice, fruit, wheat, cotton, beans, corn, peanuts, oil, potato, tea, sugarcane, hemp, tobacco and sugar. The calculated 1996-2015 years all kinds of crop water footprint values of annual mean crop water footprint to source in the province, the results are listed in table 1. For potato, tea, sugarcane, hemp, tobacco and sugar water footprint is smaller, to facilitate the analysis, the 6 kinds of plants belong to the "other crops" category.

Table 1 Water footprint and composition of various crops1996-2015

Crop	Crop production water footprint (G m^3)				Proportion (%)		
	Blue	Green	Gray	Total	Blue	Green	Gray
Wheat	11.4	13.5	5.6	30.6	37.4	44.2	18.5
Corn	1.0	14.0	4.6	19.6	5.0	71.3	23.7
Rice	0.5	0.6	0.2	1.3	38.8	44.0	17.2
Beans	0.4	1.8	0.1	2.4	17.8	76.1	6.1
Peanut	0.1	1.5	0.3	1.9	3.9	81.6	14.6
Oil	2.7	8.5	1.5	12.8	21.2	66.8	12.1
Cotton	3.3	10.4	4.4	18.1	18.2	57.4	24.5
Fruits	2.5	60.8	22.2	85.4	2.9	71.2	25.9
Other crops	0.1	0.8	0.2	1.1	4.7	75.1	20.3

Table 1 shows that the green water footprint of each crop in the province accounts for the largest proportion of its total water footprint, with an average of 74%. It shows that green water is the most important source of water resources needed for the growth and development of crops in Shandong Province, and is an important water resource base for maintaining the normal production of agricultural products in this area. Among them, the green water footprint of legumes and peanuts accounted for the largest proportion of its total water footprint, all over 80%, and the green water footprints of fruit, rice and wheat were the most, accounting for more than 70% of the total green water footprint. In addition to wheat, the blue water footprint of other crops is less than 200 million M or about 200 million M, and the proportion of blue water footprint to its total water footprint is less than 10%, indicating that the proportion of blue water in the growth and development stages of these crops is not large, which is related to the growth habits of crops and the abundant rainfall along the coast of Shandong province. In the grey water footprint, the proportion of the ash water footprint of other crops is more than 10% in addition to the bean crop, which is caused by the growth characteristics of the crops. On the other hand, the environmental pollution problem is more serious in the process of planting. Among them, the green water footprint of corn, oil and fruit crops accounts for more than 80% of the total water footprint. The growth and development mainly come from green water, and the amount of blue water is very small, which can be popularized in the area of abundant precipitation. The environmental impact of future planting needs to be considered.

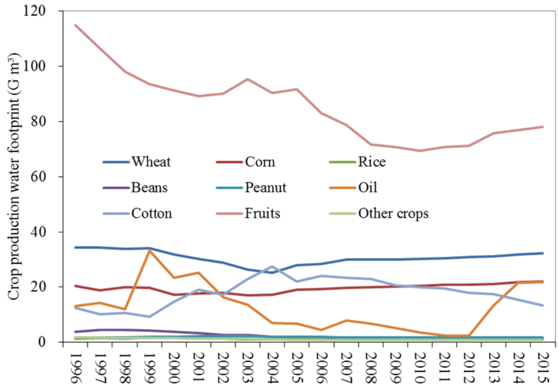

Fig. 3 Water footprint of various crops during 1996-2015

Figure 3 shows the change of water footprint of various crops over the years from 1996 to 2015. From 1996 to 2015, the water footprint of legumes, corn, peanuts and other crops changed little with the year and remained basically unchanged. The water footprint of four crops such as rice, fruit, wheat and cotton varied greatly with the year. Among them, rice decreased first and then increased steadily, and reached its minimum in 2005. After 2008, the water footprint was basically stable. The change trend of wheat was roughly the same as that of rice. The water footprint of wheat decreased from 1996 to 2005, and there was a small increase from 2005 to 2008, and it was basically stable after 2008. Fruit water footprint basically showed an upward trend, with a decrease from 2006 to 2008. The water footprint of cotton increased from 1999 to 2003 and from 2003 to 2006, and the rest years basically declined. The trend of water footprint of different crops varies with the year, in addition to the growth characteristics of the crop itself, the planting area and climatic conditions of the crops have a great relationship.

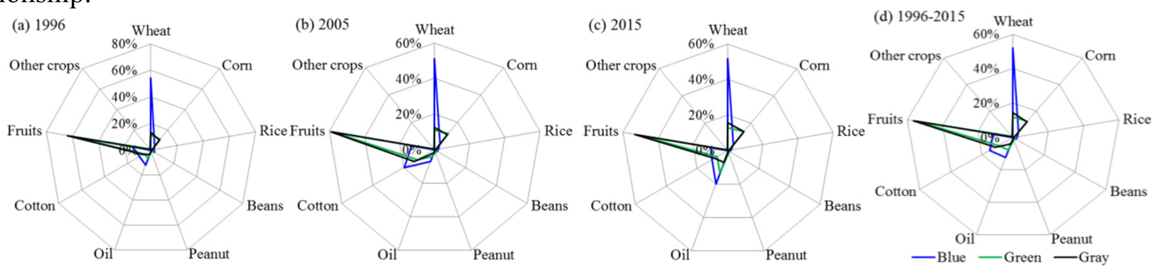

Fig. 4 Composition of blue, green and grey footprints in typical years

The blue, green, gray water footprints and total water footprints of each crop were calculated for the year of 1996, 2005 and 2015. The average value of the blue, green, grey water footprint and total water footprint of each crop from 1996 to 2015 was calculated, and Figure 4 was drawn. The proportion of the blue, green and gray water footprint of wheat, corn, peanuts and other crops remained unchanged with the annual change; the green water footprint and the gray water footprint of the fruit rose and reached the maximum in 2015; the total water footprint of the wheat reached the lowest value in 2003, blue, green and gray water footprints. The proportion of the total water footprint is also the lowest; the cotton water footprint has been declining, reaching a minimum in 2015, and the total water footprint of blue, green and gray water footprint is also the smallest.

3.3. *Driving factors of crop production water footprint*

Path analysis was used to analyse the influence of selected factors on the water footprint of single agricultural crops, and the results are listed in Table 2.

The direct factors affecting the change of crop sowing water footprint from large to small are the following: positive correlation is PCG, IRC, FA, PRH, GCY, and PCNI. The larger the PCG is, the larger the water footprint of crop sowing is, while the PCNI and IWUC are the opposite. The consistency between the total influence coefficient and the direct path coefficient is not strong, which shows that there is a negligible indirect influence between the factors and the factors. The direct path coefficient and the total influence coefficient of the amount of P, FA, FA, GCY, PRH of high water consumption crops and the proportion of the IRC are not quite different. These factors have a direct effect on the changes in the water footprints of the crops and PCG. While the direct path coefficient is larger, it also has a great influence on PCNI, IWUC, and AWR, which makes the negative correlation between the three factors become positive correlation to the crop sowing water footprint. The direct path coefficient of PCG is larger, but the total influence coefficient is small, which is mainly influenced by PCNI and IWUC.

Table 2 Path analysis results of influencing factors for crop water production footprint

Factors	Direct influence	Indirect influence										Total influence
		P	PD	PCG	PCNI	FA	GCY	IWUC	PRH	AWR	IRC	
P	-0.048		0.021	0.802	-0.512	0.035	-0.003	-0.324	0.012	0.001	0.022	-0.047
PD	-0.185	0.002		0.412	-0.071	0.037	0.001	-0.117	0.017	0.001	0.002	0.001
PCG	4.123	-0.008	-0.013		-2.4389	0.087	0.052	-2.032	0.031	0.001	0.023	0.017
PCNI	-2.4098	-0.010	-0.002	4.243		0.037	0.052	-2.206	0.025	0.001	0.041	0.010
FA	0.159	-0.003	-0.026	1.934	-0.977		0.035	-0.783	0.135	-0.003	0.172	0.651
GCY	0.072	0.002	0.003	3.425	-1.934	0.035		-1.532	0.028	0.001	0.058	0.143
IWUC	-2.1026	-0.008	-0.015	4.234	-2.335	0.087	0.04		0.012	0.001	-0.002	-0.172
PRH	0.213	-0.002	-0.017	0.662	-0.327	0.197	0.023	-0.023		0.001	0.201	0.831
AWR	-0.003	0.005	0.012	0.905	-0.465	0.026	0.020	-0.536	0.023		0.007	0.087
IRC	0.252	-0.005	-0.005	0.696	-0.437	0.149	0.217	0.026	0.126	0.002		0.917

In general, in addition to the negative correlation between the P and the irrigation water use efficiency IWUC on the crop sowing water footprint, other factors have a positive correlation. Among them, the IRC, the high PRH, the unit cultivated land area FA to the crop sowing water The influence of footprint change is the most, especially the effective irrigation area, which shows that the rational utilization of water resources, the increase of the proportion of the effective irrigation area, the reduction of the unnecessary crop sowing water footprint, and the reduction of the agricultural water pressure have an important effect. At the same time, the amount of fertilizer applied in the unit area of cultivated land directly affects the crop sowing water foot. It is also important to reduce the pollution of agricultural water by using chemical fertilizer reasonably and reducing pollution.

4. Conclusions

The crop production water footprint can be analysed from the angle of water consumption by blue and green water footprint, and can be analysed from the angle of pollution through the ash water footprint, thus the real demand of the regional agricultural production process to the water footprint can be better measured. Besides, accounting and studying regional crop production water footprint can comprehensively evaluate the real impact of agricultural production process on water resources system. Although the crop production water footprint in Shandong remains stable, the average value of the crop is still more than 17 billion. Most of the water was consumed by rice, fruit and wheat. The rational distribution and management of crop water consumption, the improvement of the effective irrigation area, and the reduction of high water consumption crops will be the key areas of agricultural development. . At the same time, the proportion of ash water footprint accounts for 20% of the total water footprint. It is important to optimize the planting structure, improve the production technology and reduce the use of chemical fertilizer, reduce the planting proportion of the higher grey water footprint, and also to reduce the crop ash water footprint and maintain the balance of the agricultural production environment.

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