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Study of the Spatial and Temporal Patterns of the Water Footprint of Grain Production in the Huaihe River Basin

Zhenying Huang[1,*], Jinjin Hu[2]

[1]School of Economics, Anhui University of Finance and Economics, Bengbu, China

[2]Haojing College of Shaanxi University of Science and Technology, Xian, China

*huangzhenying311@163.com

Abstract

In this paper, the theories related to water footprint were sorted out and the contents included in the water footprint of grain production were identified. According to the quantification method of water footprint of grain production, the water footprint of grain production in the Huaihe River basin from 2000-2019 was accounted for using CropWat 8.0 by combining the collected data parameters related to grain, climate, soil, pollutant loss rate and leaching rate. The results showed that the multi-year average of wheat growth water footprint was 47.466 billion m3, with an overall increasing trend; the multi-year average of rice growth footprint was 21.554 billion m3, with an average annual increase rate of 416 million m3; the multi-year average of maize growth water footprint was 14.010 billion m3, with an average annual increase rate of 665 million m3; the multi-year average of soybean growth water footprint was 3.952 billion m3, with an annual Finally, based on the water footprint of grain production in the Huaihe River basin, the spatial and temporal patterns of the water footprint of grain production were analyzed using ArcGIS10.2 geographic information analysis software3. The results show that the spatial distribution of the water footprint of wheat production varies greatly, the water footprint of rice growth shows the distribution characteristics of "high in the east and low in the west" and "high in the south and low in the north", the water footprint of maize growth shows the distribution characteristics of "high in the north and low in the south The water footprint of maize growth shows "high north and low south" distribution characteristics, and the water footprint of soybean growth shows "low-high" clumped distribution characteristics.

Keywords

Huaihe River Basin; Water footprint of grain production; Spatial and temporal patterns.

1. Introduction

Human life and production cannot be separated from water, and the development of both agricultural and non-agricultural sectors requires a certain level of water security (Wang,et al., 2020) [1]. In recent years, both human activities and climate change have created significant challenges to water availability (Schewe, 2014) [2]. Agriculture uses 85% of the global surface and groundwater and is the main source of water consumption in the world (Vörösmarty, 2010) [3]. Water scarcity likewise constrains agricultural production and food security in China (Wu, 2017) [4].In 2019, China's total water consumption was 602.12 billion m^3, of which 368.23 billion m^3 was used for agriculture, and more than 50% of farmland was not effectively irrigated, and the large amount of water used for agriculture was accompanied by a shortage of water for farming (Ministry of Water Resources of the People's Republic of China, 2019) [5]. China's rapid economic development has brought about a series of new shortages of water resources, among which the reduction of available water resources due to environmental pollution is more serious (Tang, 2019) [6]. In this context, the State promulgated the China Water Pollution Prevention and Control Action Plan, however, the current pressure on China's water resources is still not negligible due to the impact of climate change (Sun, 2018) [7]. The multiple factors that make it difficult to artificially control the total amount of water resources, the high total amount of agricultural water consumption, the unbalanced spatial distribution of water resources, and the mismatch between regional economic development and water resources will inevitably lead to the continuous challenge of water consumption for agricultural production in China (Zhou,2021) [8].

Agriculture is a basic industry that solves the food and clothing of all people and is concerned with the development and stability of the world (Cao, 2014) [9]. Food production consumes a large amount of water resources, and water endowment and utilization efficiency also determine the ability to produce food (Chen, 2020) [10]. The severe shortage of agricultural water resources coexists with inefficient utilization, which restricts the development of grain production in China (Yuan, 2020) [11]. The proportion of water used for grain production in total agricultural and non-agricultural water use in China decreased from 51% in 1997 to 42% in 2016, with non-agricultural water use crowding out water for grain production (Li, 2018) [12]. The crude agricultural irrigation method makes the waste of water resources more serious (Bo, 2016) [13]. The waste of water resources pollution caused by chemical fertilizers and pesticides is equally huge (Li, 2015) [14]. Improving irrigation practices on farmland and reducing water pollution are key to improving water efficiency in food production (Gordon, 2011) [15]. Improving water use efficiency for food production is an important focus point for resolving regional water conflicts in China.

The Huaihe River Basin is the main grain production base in China, with a sown area of 19,783,600 hectares of grain crops in 2019, accounting for 17.05% of the country, and a total grain output of 124,325,100 tons, accounting for 18.73% of the country. Four crops - wheat, rice, corn and soybeans - account for more than 90% of grain production in the Huaihe River Basin. In 2018, the Huaihe River Basin became a strategic development zone at the national level for the first time in China, and has since made a historic shift from simply "managing the flooding of the Huai River" to comprehensive sustainable development. *The Huaihe River Ecological and Economic Development Plan* clearly states that economy is the link and ecology is the premise. Therefore, on the premise of ensuring the stable development of grain production in the Huaihe River basin, improving water efficiency for grain production and improving the current situation of water wastage are the key issues for the development of grain industry in the Huaihe River basin in the future.

Given the importance of the Huaihe River Basin's grain production status, the limited water resources, and the water-grain mismatch, this paper accounts for the water footprint of grain production in the Huaihe River Basin and explores the characteristics and patterns of water use for grain production.

2. Theoretical Analysis

The water footprint theory was first introduced in 1993 by Allan, a British scholar, who proposed the concept of "virtual water", which was used to measure the amount of water required to produce agricultural products. Later, Dutch scholar Hoekstra (2003) [16] extended the concept of "virtual water" and proposed the amount of water consumed in the production of certain products (goods, services, etc.), which was later known and widely used by scholars in various countries as the "water footprint". In food production, water consumption includes the water consumed by the crop itself for growth (food growth water footprint) (Xu, 2019) [17], and the water consumed to accommodate the pollutants produced (food gray water footprint) (Shervin, 2020) [18]. In this paper, we use the CropWat 8.0 calculation recommended by the

Food and Agriculture Organization of the United Nations (FAO) to measure the grain growth water footprint and refer to the *Water Footprint Evaluation Handbook* (Hoekstra, 2012) [19] to quantify the gray water footprint.

2.1. Quantification of the water footprint of food growth theory

2.1.1. Evapotranspiration of reference crops

It is assumed that the evapotranspiration rate of a reference crop in the absence of water deficit is called the reference crop evapotranspiration. ETo can be measured based on the Penman-Monteith model embedded in CropWat 8.0 software in combination with climatic parameters (including wind speed, air temperature, air humidity and sunshine hours). The measurement equation is as follows.

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{1}$$

Where ETo is the reference crop evapotranspiration (mm/day), R_n is the net radiation from the reference crop surface [MJ/(m^2-day)], G is the soil heat flux density [MJ/(m^2-day)], T is the average air temperature at 2 m height near the ground (C), U_2 is the wind speed at 2 m height near the ground, e_s-e_a is the saturation pressure difference (kPa), Δ is the slope of the pressure curve (kPa/C), and γ is the humidity constant (kPa/C).

2.1.2. Evapotranspiration of standard food crops

The evapotranspiration of a food crop when full growth has been achieved under optimal soil moisture conditions on the farm is called standard food crop evapotranspiration (ETc). etc can be calculated based on ETo and the crop growth coefficient and is calculated as follows.

$$ETc = ETo \times Kc \tag{2}$$

Where ETc is the standard food crop evapotranspiration (mm/day) and Kc is the food crop growth coefficient.

2.1.3. Water requirements for growing food crops

CWR refers to the water consumption of the whole process of planting-growing-harvesting of food crops, which can be calculated based on ETc with the following formula.

$$CWR = 10\sum_{d=1}^{n} ETc \tag{3}$$

Where CWR is the water requirement for food crop growth (m^3/hm^2), $\sum_{d=1}^{n} ETc$ is the sum of ETc per day from sowing to harvest (mm), and 10 is the constant factor, which is the unit conversion factor that converts water depth units (mm) into water volume per unit area (m^3/hm^2).

2.1.4. Regional food and water footprint

The regional food water footprint is calculated as follows.

$$TW_{i,j} = \frac{CWR_{i,j}}{y_{i,j}} \times Y_{i,j} \tag{4}$$

Where, $TW_{i,j}$ for i region j grain water footprint (m^3), $CWR_{i,j}$ for i region j grain crop unit area growth of water demand (m^3/hm^2), $y_{i,j}$for i region amount j grain unit area yield (kg/hm^2), $Y_{i,j}$ for i region j grain yield (kg).

2.2. Theory of quantifying the grey water footprint of food

Hoekstra et al. (2008) [20] first introduced the concept of gray water footprint and introduced the quantification method of gray water footprint in a subsequent study. Pollutants to water bodies during the growth of food crops originate from chemical fertilizers and pesticides, while pesticide use is much lower than that of chemical fertilizers (Bao, 2020) [21]. Pollution of water bodies depends on the ease of dissolving unabsorbed fertilizers in water bodies (Chen, 2020) [10], with potassium and phosphorus not easily dissolved in water bodies and nitrogen very easily dissolved in water bodies causing pollution (Gai, 2010) [23]. According to the "short board principle" of gray water footprint, that is, the gray water footprint should be determined by the pollutant that requires the largest amount of diluted water, and considering the unavailability of pesticide data (including pesticide types, different pesticide loss rates, etc.), only nitrogen fertilizer is used as a pollutant to calculate the gray water footprint of grain in this paper. Referring to the relevant study (Cao, 2014) [9], the grain gray water footprint is calculated as

$$GW_{i,j} = (\alpha_j \times \tau_j \times S_{i,j})(C_{\max} - C_{nat}) \tag{5}$$

Where GW_{ij} is the gray water footprint of the jth grain in region i, α_j is the nitrogen fertilizer leaching rate of the jth grain crop, τ_j is the amount of nitrogen fertilizer applied per unit area of the jth grain crop, S_{ij} is the yield of the jth grain crop in region i, C_{max} is the highest nitrogen fertilizer concentration that the environment can accommodate, and C_{nat} is the background concentration of nitrogen fertilizer in the natural environment.

3. Data Parameters

3.1. Parameter determination

3.1.1. Grain phenology parameters

Grain production in the Huaihe River Basin is dominated by wheat, summer maize, rice and soybean, and the four crops account for more than 90% of grain production; therefore, the grain crops referred to in this paper are only these four crops. Combined with the research results of similar regions (Sun et al., 2019; Gao et al., 2019) [25,26], the initial sowing dates of major grain crops in the Huaihe River basin were determined by comparing the self-contained database of the Food and Agriculture Organization of the United Nations (FAO) CROPWAT 8.0 to obtain the phenological information (Table1)

Table1. Phenological parameters of grain production in the Huaihe River Basin

Main food crops	Sowing and harvesting time			Sowing-harvesting crop coefficient (Kc)		
	Planting date	Harvest date	Number of days	Initial period	Mid-term	Final
Wheat	October 11	June 7 of the following year	240 days	0.7	1.15	0.25
Rice	June 11	Oct. 8	150 days	1.1	1.2	1.05
Corn	June 12	Oct. 14	125 days	0.3	1.2	0.35
Soybeans	June 10	September 2	85 days	0.4	1.15	0.5

Note:Grain crop growth times and Kc were obtained from the CROPWAT 8.0 database.

3.1.2. Soil parameters

According to China Institute of Soil Sciences（ http://www.soil.csdb.cn ）The published data of soil types in 28 prefecture level cities were compared with cropwat8 0 determination parameters of similar soil types in the soil database (including total effective soil water content, mm / M; heavy rainfall infiltration rate, mm / day; maximum rooting depth, cm; initial soil water consumption rate,%; initial soil humidity, mm / M).

3.1.3. Greywater footprint parameters

The parameters of grain gray water footprint in the Huaihe River basin include nitrogen fertilizer leaching rate α, nitrogen fertilizer application rate per unit area τ, the maximum nitrogen fertilizer concentration that the environment can accommodate C_{max}, and the background concentration of nitrogen fertilizer in the natural environment C_{nat}. In this paper, referring to the studies of Han(2019) [27] and Liu (2019) [28], we determined that wheat, rice, maize, and soybean α were 10%, 14%, 12%, and 5%, respectively; τ was 139, 135, 119, and 109 kg/hm^2, respectively; C_{max} was determined as 0.02 kg/m^3 according to the *Chinese Groundwater Quality Standard* (GB/T14848-2017); and C_{nat} was taken as the minimum value of zero.

3.2. Data source

3.2.1. Agricultural production data

The study area of this paper is 28 prefecture-level cities in the Huaihe River Basin, with a time series of 2000-2019, and the study object is grain (wheat, rice, corn and soybean). Agricultural production data, including grain crop production and grain crop unit area production, are obtained from the provincial *Statistical* Yearbooks of the provinces where the 28 prefecture-level cities in the Huaihe River Basin are located, where missing data are filled in by the *Jiangsu Rural Statistical Yearbook*, the *Hubei Rural Statistical Yearbook* and the municipal *Statistical Yearbooks*.

3.2.2. Meteorological Data

Meteorological data were provided by China Meteorological Data Network. Given that some prefecture-level cities within the 28 prefectures in the Huaihe River basin have no meteorological station distribution, meteorological data from 25 meteorological stations in the Huaihe River basin from 2000-2019 were selected, and some neighboring regions shared station data (e.g. Zhoukou City shared Bozhou Station, Luohe City shared Baofeng Station meteorological data, etc.) (Table2). The meteorological information includes six meteorological elements, including average 2-minute wind speed (m/s), average maximum temperature (C), average minimum temperature (C), average relative humidity (%), precipitation at 20-20 hours (mm), and sunshine hours (h).

Table2. Distribution of meteorological stations in the Huaihe River Basin

Province	Site
Anhui	Shouxian, Bengbu, Bozhou, Chuzhou, Fuyang, Liuan, Mengcheng, Suizhou
Henan	Nanyang, Xinyang, Zhumadian, Shangqiu, Baofeng
Shandong	Linyi, Heze, Yanzhou, Feixian
Jiangsu	Gaoyou, Sihong, Xuzhou, Huaian, Ganyu, Dafeng
Hubei	Suizhou, Xiaogan

4. Empirical Analysis

Based on the water footprint theory, this paper quantifies and analyzes the water footprint of food production in the Huaihe River basin, explores the characteristics of the spatial and temporal patterns of the water footprint of food production in the Huaihe River basin from the perspectives of time series change and spatial pattern evolution, respectively, and describes the evolution law of the water footprint pattern of food production.

4.1. Time series analysis of the water footprint of grain production in the Huaihe River Basin

According to the previous water footprint quantification method, the water footprint of food crop production was calculated using CropWat 8.0, combined with relevant data parameters (Table3). 2000-2019 in the Huaihe River basin includes the water footprint of grain growth (TW) and the gray water footprint of grain (GW), of which the average TW in the last 20 years is 87.912 billion m^3, with an overall fluctuating upward trend, with an average of 1.996 billion m^3 The average TW over the past 20 years is 87.912 billion m^3, with an overall fluctuating upward trend and an average annual increase of 1.996 billion m^3. In the past 20 years, the average GW was 4.810 billion m^3, with an overall slow upward trend and an average increase of 102 million m^3 per year.

Table 3. Water footprint of food production in the Huaihe River Basin, 32000-2019 (billion m3)

	2000		2003		2006		2009		2012		2015		2019	
	GW	TW	GW	TW	GW	TW	GW	TW	GW	TW	GW	TW	GW	TW
Huaibei	5.74	0.40	7.34	0.40	9.59	0.47	10.82	0.56	11.85	0.53	11.18	0.60	11.58	0.67
Bozhou	26.32	1.34	23.37	1.33	34.07	1.60	37.39	1.92	40.63	1.92	40.23	1.97	51.36	2.17
Cebu	28.89	1.48	25.99	1.45	32.24	1.67	34.89	1.82	39.67	1.92	37.83	2.02	51.37	2.34
Bengbu	20.02	0.95	18.37	0.99	23.59	1.18	23.32	1.30	26.73	1.29	26.21	1.38	31.09	1.50
Fuyang	33.73	1.83	31.52	1.95	40.93	2.14	41.49	2.41	51.80	2.48	46.02	2.62	58.83	2.53
Huainan	19.44	1.04	17.10	0.97	25.54	1.31	25.90	1.38	28.04	1.34	23.37	1.36	32.59	1.70
Chuzhou	30.35	1.63	26.68	1.62	35.76	2.03	35.60	2.15	39.77	2.25	37.93	2.33	49.35	2.65
Lu'an	22.30	1.15	18.60	1.15	26.42	1.42	25.89	1.49	30.06	1.56	27.65	1.70	38.65	2.06
Pingdingshan	15.40	0.95	15.62	0.99	16.80	1.00	18.00	1.06	19.96	1.08	19.85	1.12	23.43	1.19
Luohe	10.05	0.61	10.03	0.63	11.26	0.66	11.88	0.69	13.27	0.71	13.04	0.72	14.43	0.68
Nanyang	40.17	2.30	34.77	2.25	48.22	2.58	48.37	2.84	60.83	2.96	61.45	3.14	75.33	3.48
Shangqiu	32.41	1.96	31.10	2.03	37.96	2.29	40.57	2.39	44.76	2.51	43.96	2.71	55.52	2.94
Xinyang	35.40	2.09	32.23	2.03	44.18	2.48	42.41	2.59	48.02	2.68	47.96	2.76	55.25	2.73
Zhoukou	45.66	2.40	39.92	2.32	50.48	2.56	52.35	2.85	60.25	3.00	61.03	3.20	81.90	3.57
Zhumadian	38.49	2.37	40.61	2.60	49.88	2.89	54.14	3.10	54.45	3.23	55.84	3.35	70.21	3.55
Zaozhuang	9.76	0.57	7.19	0.46	11.74	0.69	12.68	0.74	12.33	0.74	12.09	0.70	13.66	0.76
Jining	32.70	1.76	23.42	1.44	25.53	1.57	30.13	1.77	30.57	1.82	31.00	1.79	34.76	1.93
Linyi	31.48	1.84	22.95	1.45	30.36	1.77	35.65	1.87	34.18	1.93	31.52	1.75	34.38	1.68
Heze	30.99	1.76	24.23	1.47	41.07	2.45	47.99	2.81	50.30	2.67	48.57	2.70	66.45	3.28
Xuzhou	30.26	1.66	20.37	1.30	32.39	1.80	36.19	2.02	41.71	2.16	38.91	2.18	42.20	2.24
Lianyungang	20.84	1.14	17.63	1.08	23.73	1.36	26.28	1.47	27.48	1.54	27.24	1.56	29.01	1.60
Huai'an	26.30	1.46	21.27	1.41	35.89	1.93	37.34	2.02	38.78	2.07	31.26	2.08	39.25	2.16
Yancheng	36.06	2.03	28.33	1.73	40.86	2.21	41.92	2.40	48.60	2.58	45.54	2.89	61.56	2.98
Yangzhou	19.40	1.03	19.10	1.01	22.06	1.10	24.35	1.25	26.98	1.33	24.22	1.33	23.46	1.23
Taizhou	22.32	1.18	21.41	1.13	25.31	1.26	25.40	1.30	26.41	1.30	24.39	1.34	22.35	1.17
Suqian	22.54	1.49	21.59	1.34	29.73	1.61	28.28	1.73	28.94	1.70	30.66	1.78	27.82	1.86
Xiaogan	13.93	0.96	14.66	0.85	20.39	1.04	20.80	1.11	21.65	1.13	22.27	1.17	18.21	1.19
Suizhou	6.40	0.51	7.56	0.46	12.67	0.66	11.54	0.67	12.55	0.69	12.47	0.73	7.79	0.65

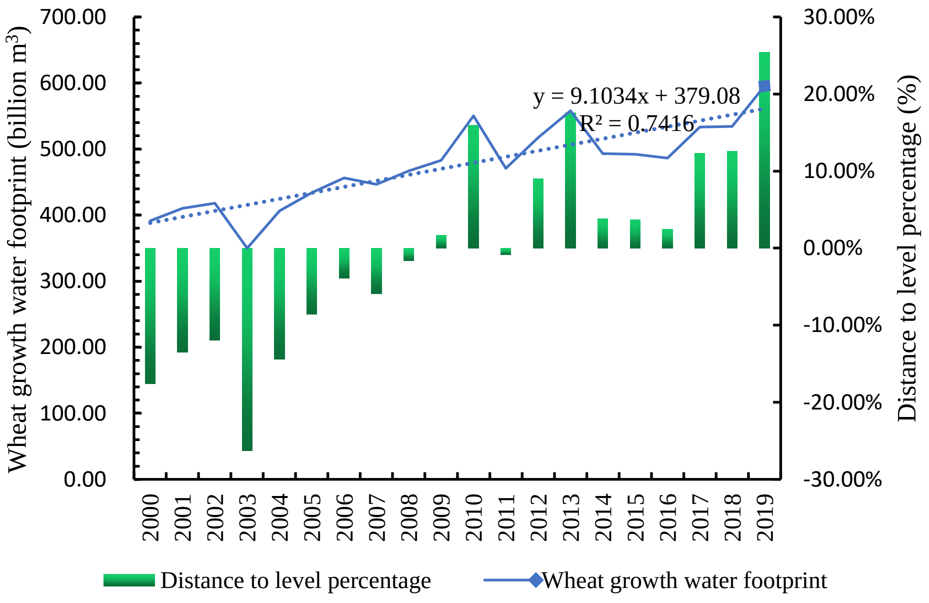
Note:Due to limited page width, only partial year data are listed.

4.1.1. Time series variation in the water footprint of wheat production

Grain growth water footprint is mainly influenced by two factors, effective precipitation and crop yield per unit area. 2000-2019, the average value of wheat growth water footprint time series in the Huaihe River basin was 47.466 billion m^3, with an overall upward trend and an average annual increase of 910 million m^3. Among them, the highest value was 59.548 billion m^3 in 2019, a year with more rainfall and higher effective rainfall. The lowest value was 34.994 billion m^3 in 2003, a year with relatively less precipitation and lower yield per unit area of wheat. The gray water footprint of crop production is mainly influenced by two factors: fertilizer application and crop yield per unit area. The average value of the gray water footprint of wheat in the Huaihe River basin from 2000 to 2019 is 2.448 billion m^3 and fluctuates upward with a trend of 0.037 billion m^3 per year. The lowest value was 1.918 billion m^3 in 2003, and the highest value was 2.659 billion m^3 in 2018. The percentage difference between the distance level of growth water footprint and gray water footprint of wheat in the Huaihe River basin in each year was large, indicating a large inter-annual difference, and the growth water footprint of wheat was much higher than the gray water footprint, indicating that the growth water footprint plays a crucial role in wheat production.

4.1.2. Time series variation of water footprint of rice production

In2000-2019, the interannual variation of the water footprint of rice production in the Huaihe River basin is shown in Fig2. The multi-year mean rice growth footprint was 21.554 billion m^3, with an average annual rise rate of 416 million m^3. The green water footprint of rice production fluctuated in the range of 15.189-26.210 billion m^3 in each year, with the smallest rice growth footprint in 2003 and the largest in 2019. The multi-year average of rice gray water footprint in the Huaihe River basin was 1.298 billion m^3, fluctuating upward with a trend of 0.025 billion m^3 per year, and the rice gray water footprint fluctuated within the range of 0.996-1.524 billion m^3 in each year, with the smallest rice gray water footprint in 2003 and the largest water footprint in 2018. The interannual difference between rice and wheat growth water footprints was smaller in terms of the percentage of rice production water footprint distance from 2000-2019.



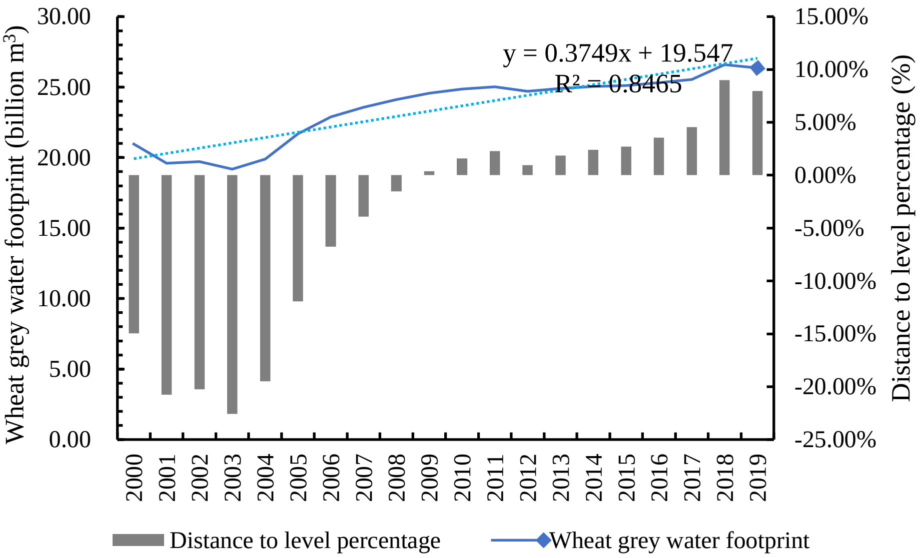
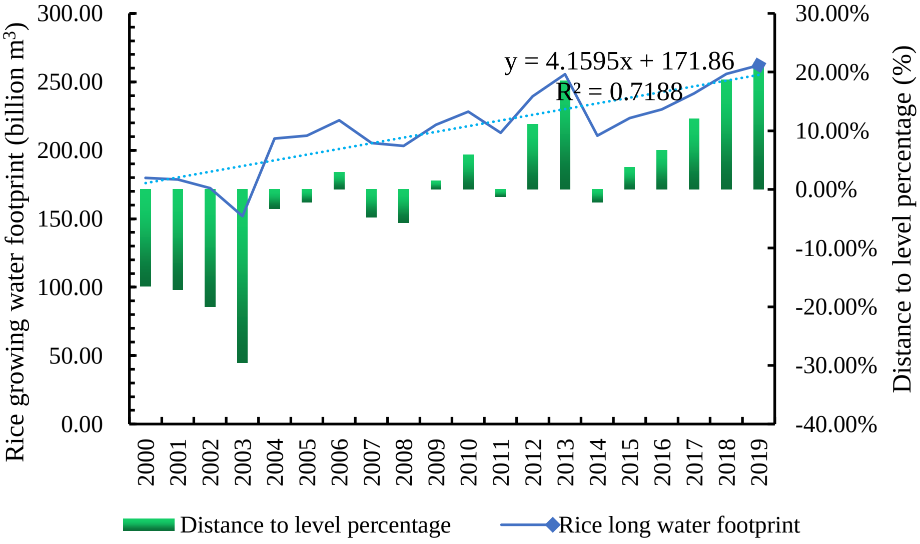


Figure 1 Time series variation of wheat water footprint in the Huaihe River Basin, 2000-2019

Note: Distance level percentage: (measured value - historical average)/historical average, which can clearly reflect the size of interannual variation in water footprint.

4.1.3. Time series variation in the water footprint of maize production

In 2000-2019, the multi-year average of maize growing water footprint in the Huaihe River basin was 14.010 billion m^3, with an average annual rise rate of 665 million m^3. The maize growing water footprint fluctuated in the range of 82.88-21.791 billion m^3 in all years. Among them, the green water footprint of summer maize production was the smallest in 2003 and the largest in 2019. The multi-year average of corn gray water footprint was 1.030 billion m^3, fluctuating upward with a trend of 0.041 billion m^3 per year, and fluctuating in the range of 0.673-1.405 billion m^3 for each year. The smallest corn growth water footprint was in 2000 and the largest water footprint was in 2018. The interannual fluctuation of maize growth water footprint and gray water footprint from the distance level percentage is large, and maize is a typical rain-fed agriculture, which is influenced by meteorological conditions, resulting in an overall fluctuating upward trend of maize production water footprint (Figure 3).



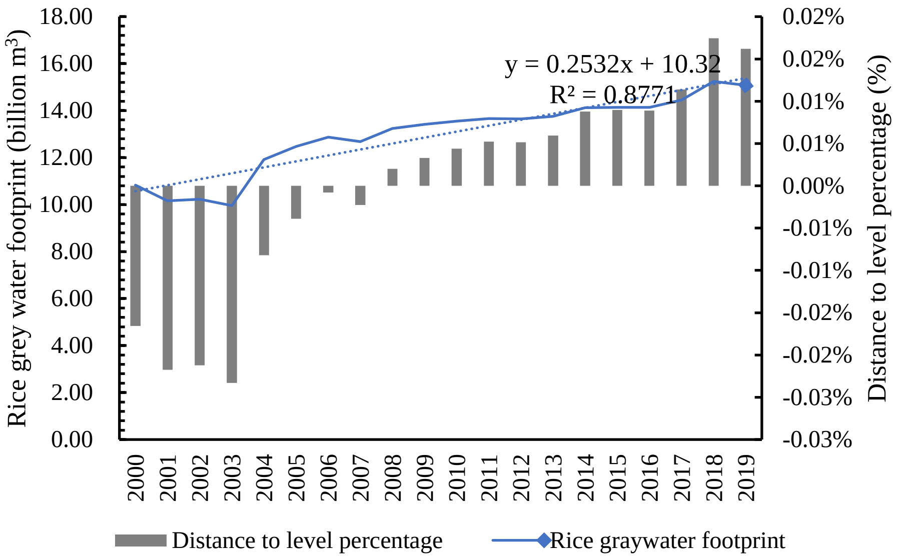


Figure2. Time series variation of rice water footprint in the Huaihe River Basin, 2000-2019

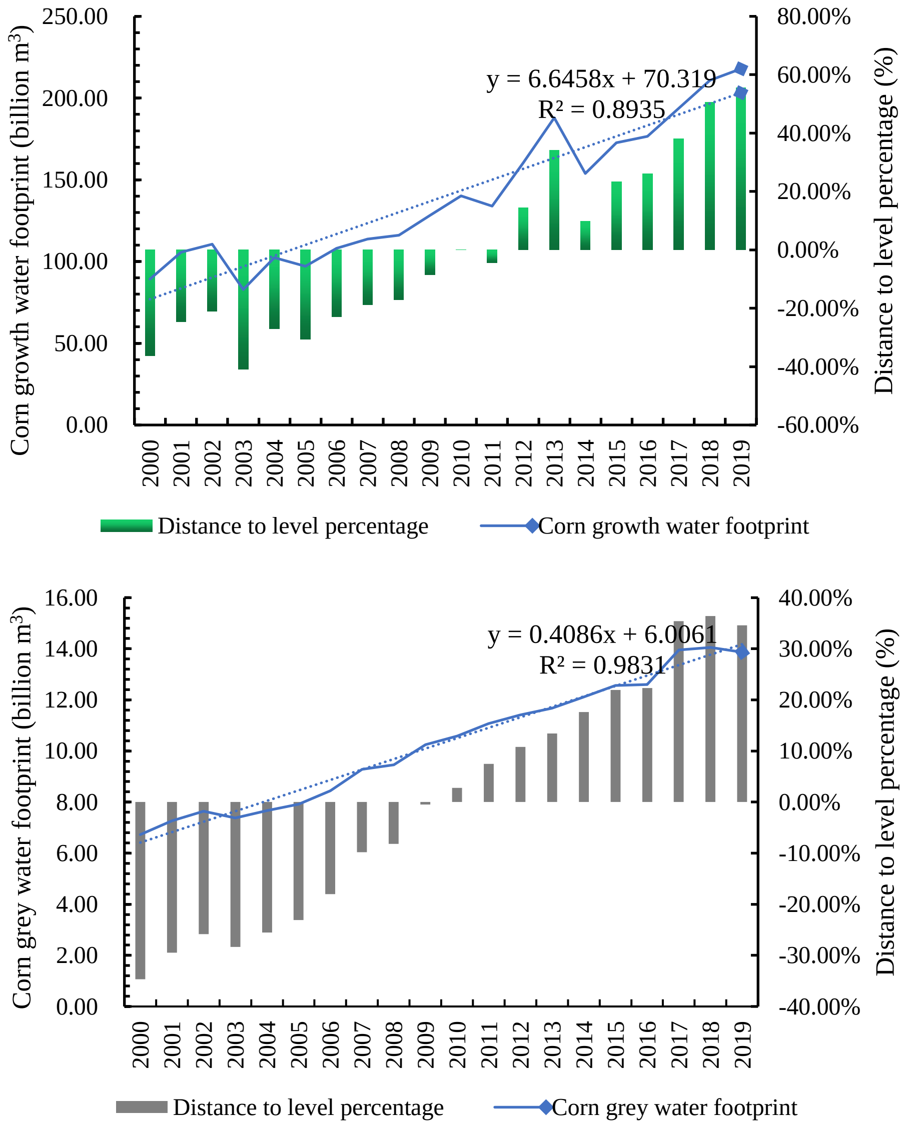


Figure3. Time series variation of corn water footprint in the Huaihe River Basin, 2000-2019

4.1.4. Time series variation in the water footprint of soybean production

In 2000-2019, the multi-year average water footprint of soybean growth in the Huaihe River Basin was 3.952 billion m^3, with an average annual decline rate of -0.008 billion m^3. The green water footprint of fall soybean production fluctuated in the range of 3.143-5.481 billion m^3 in all years. The green water footprint of fall soybean production was the largest in 2013 and the smallest in 2003. The soybean gray water footprint has a multi-year average of 134 million m^{3}and fluctuates downward with an annual trend of one million m^3. The fall soybean production blue water footprint fluctuates within the range of 113-162 million m^3 for each year, with the smallest for soybean in 2016 and the largest in 2007. The percentage of the distance level of the soybean production water footprint shows small interannual fluctuations in the growth water footprint and large fluctuations in the gray water footprint (Figure 4).

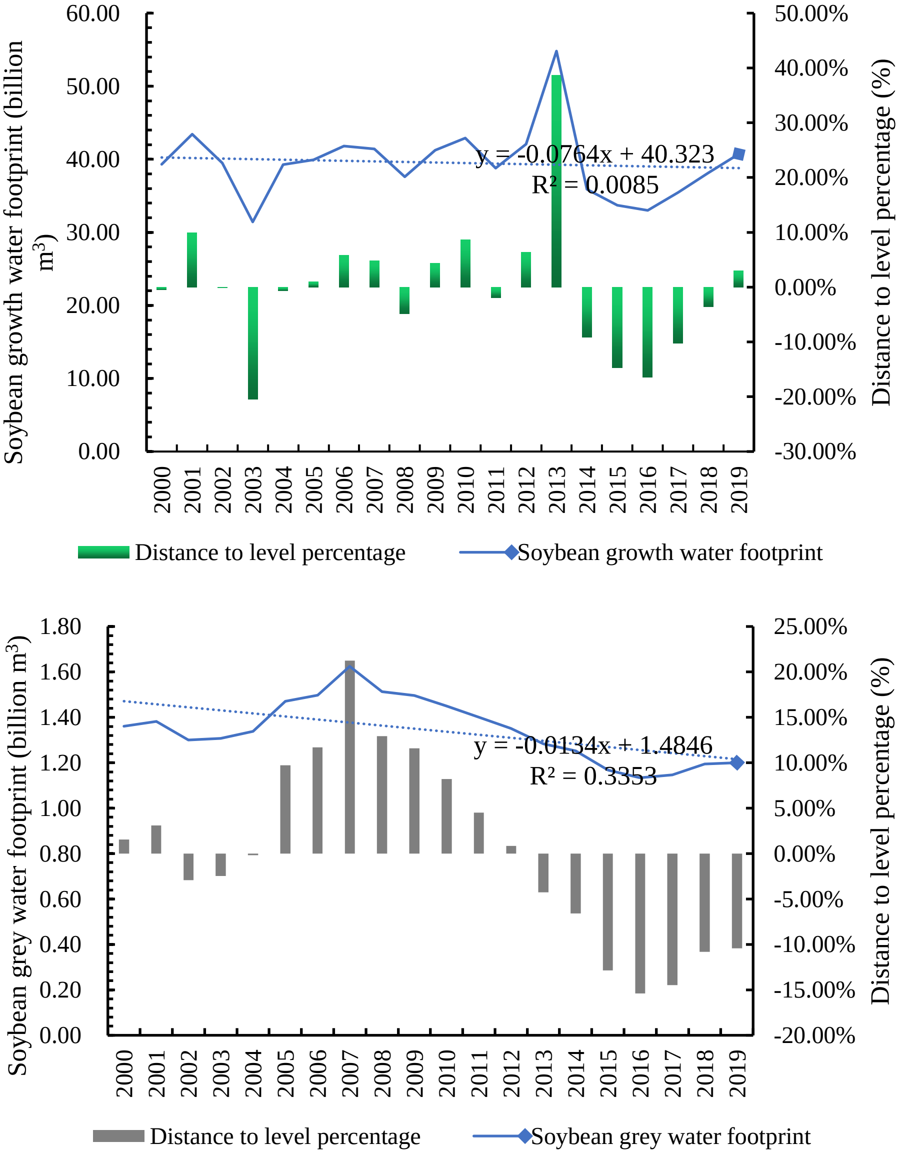


Figure4. Time series change in soybean water footprint in the Huaihe River Basin, 2000-2019

4.2. Analysis of the spatial pattern of water footprint of grain production in the Huaihe River Basin

Based on the quantification results of the water footprint of 28 prefecture-level cities in the Huaihe River basin from above 2000 to 2019, it was found that the overall spatial distribution characteristics of the water footprint of grain production were "high in the north and low in the south". With the help of Arcgis 10.2 software, the spatial distribution characteristics of the water footprints (growth water footprint and gray water footprint) of wheat, rice, corn and soybean production are shown.

4.2.1. Wheat production water footprint characteristics

The regional water footprint of grain production is determined by many factors such as effective precipitation, irrigation, fertilizer application rate and crop yield per unit area, and therefore, the combined influence of these factors leads to large differences in the spatial distribution of the water footprint of wheat production in the Huaihe River Basin. In terms of the water footprint of wheat growth, the high water footprint area is mainly concentrated in the northwest of the Huaihe River Basin in Henan and Shandong Province, specifically including four prefectures such as Nanyang, Zhumadian, Zhoukou and Heze, all above 3.607 billion m^3, with the highest value reaching 5.255 billion m^3. The middle value area of 0.810-3.606 billion m^3 is mainly located in the central part of the Huaihe River Basin, mainly with Fuyang, Shangqiu, Linyi and other A total of 20 prefecture-level cities; the low value area below 809 million m^3 is mostly in the southwest of the Huaihe River basin in Hubei Province, mainly in Suizhou, Xiaogan, Huabei and Zaozhuang, a total of four prefecture-level cities. Relatively little precipitation during the wheat reproductive period, so that precipitation to wheat growth water needs to meet the lower degree, for the four high-value areas, the region's higher wheat yields at the same time, less precipitation, resulting in higher water needs, water footprint high and low distribution phenomenon is the main reason. In terms of wheat gray water footprint, the distribution of high and low value areas is generally similar to the growth water footprint, with the high value area of 140-219 million m^3 including Shangqiu, Heze, Nanyang and other 5 prefecture-level cities; the medium value area of 45-139 million m^3 is more distributed, including Lianyungang, Linyi, Fuyang and other 17 prefecture-level cities; the low value area of 10-44 million m^3 includes Suizhou, Xiaogan, Huabei A total of 6 prefecture-level cities, including Suizhou, Xiaogan and Huibei. By comparing the gray water footprints of wheat in each prefecture-level city, we found that the reason for the different distribution of gray water footprints is the size of wheat yield, and the high wheat yield results in the high application of nitrogen fertilizer, which leads to the different distribution of high-value areas and low-value areas.

4.2.2. Rice production water footprint characteristics

From the perspective of the rice growing water footprint, the high and low value areas have obvious spatial differentiation characteristics, specifically showing the distribution characteristics of "high in the east and low in the west" and "high in the south and low in the north". 1.967 billion m^3 of high value areas are mainly in Chuzhou, Liu'an, Yancheng, Xinyang, a total of 4 prefecture-level cities. The highest value is 3.425 billion m^3 in Xinyang City; the middle value area of 0.036-1.966 billion m^3 is mainly in Nanyang City, Bengbu, Xuzhou and other 15 prefecture-level cities; the low value area below 0.035 billion m^3 is mainly in Huabei, Shangqiu, Suizhou and other 9 prefecture-level cities. In terms of the rice gray water footprint, the distribution of high and low value areas is basically consistent with the growing water footprint. By comparing rice cultivation at each prefecture level, we found that there are two main reasons for the different distribution of gray water footprints: first, rice requires higher water and heat conditions, and more rice is cultivated in the southern part of the Huaihe River Basin with higher yields; second, it may be due to the influence of local food crop cultivation habits restricted to the area.

4.2.3. Characterizing the water footprint of maize production

In terms of the water footprint of maize, the spatial differentiation of high and low value areas is generally opposite to that of rice, showing the distribution characteristics of "high in the north and low in the south". The medium value area of 1.386 billion m^3 mainly includes Suqian, Huabei, Luohe and other total 13 prefecture-level cities; the low value area of less than 173 million m^3 mainly includes Taizhou, Suizhou, Huainan and other total 10 prefecture-level cities. From the corn gray water footprint, the distribution of high and low value areas is slightly different from the growing water footprint, the high value area above 0.86 billion m^3 is mainly in Shangqiu, Zhumadian, Nanyang and other total 5 prefecture-level cities, and the highest value is 153 million m^3 in Heze; the medium value area of 0.009-0.086 billion m^3 is mainly in Suqian, Huabei, Luohe and other total 15 prefecture-level cities; the low value area below 0.008 billion m^3 is mainly in Yangzhou, Taizhou, Huainan, etc. a total of 8 prefecture-level cities.

4.2.4. Soybean production water footprint characteristics

From the perspective of soybean growth water footprint, the spatial characteristics of high and low value areas are not obvious, and generally show a "low high" cluster distribution. The high-value areas above 176 million m^3 mainly include four prefecture level cities, including Zhoukou, Fuyang and Suzhou, with the highest value of 587 million m^3 in Bozhou; The median area of 25-175 million m^3 mainly includes 19 prefecture level cities such as Zaozhuang, Taizhou and Yangzhou; Low value areas below 24 million m^3 mainly include five prefecture level cities such as Xiaogan, Lianyungang and Xinyang. From the perspective of soybean grey water footprint, the regional distribution of high and low value is similar to that of growth water. The high value areas with more than 8 million m^3 are mainly located in Anhui Province, including four prefecture level cities such as Fuyang, Bozhou and Suzhou, with the highest value of 16 million m^3 in Suzhou; The median area of 2-7 million m3 mainly includes 13 prefecture level cities such as Huainan, Zhumadian and Heze; Low value areas below 1 million m3 mainly include 11 prefecture level cities such as Lianyungang, Xiaogan and Xinyang.

5. Conclusion

By accounting for the water footprint of food production in the Huaihe River Basin and analyzing the spatial and temporal evolution, the following conclusions were drawn.

(1) The water footprint of food production in the Huaihe River Basin increased year by year from 2000 to 2019. The average TW of the last 20 years is 87.912 billion m^3, with an overall fluctuating upward trend, increasing year by year with an average increase of 1.996 billion m^3. The average GW of the last 20 years is 4.810 billion m^3, with an overall slow upward trend, increasing year by year with an average increase of 102 million m^3.

(2) In the water footprint of food production in the Huaihe River Basin, wheat> rice> corn>soybean; except for soybean, the growing water footprint and gray water footprint of the other three food crops are increasing year by year.

(3) The overall spatial distribution of water footprint of grain production in the Huaihe River Basin shows the characteristics of "high in the north and low in the south", and the spatial differentiation of water footprint of four grain crops - wheat, rice, corn and soybean - is obvious, and the growth water footprint and gray water footprint have similar spatial distribution characteristics.

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