Analysis on temporal and spatial differences of the water footprint of wheat in 30 years in Yellow River Basin

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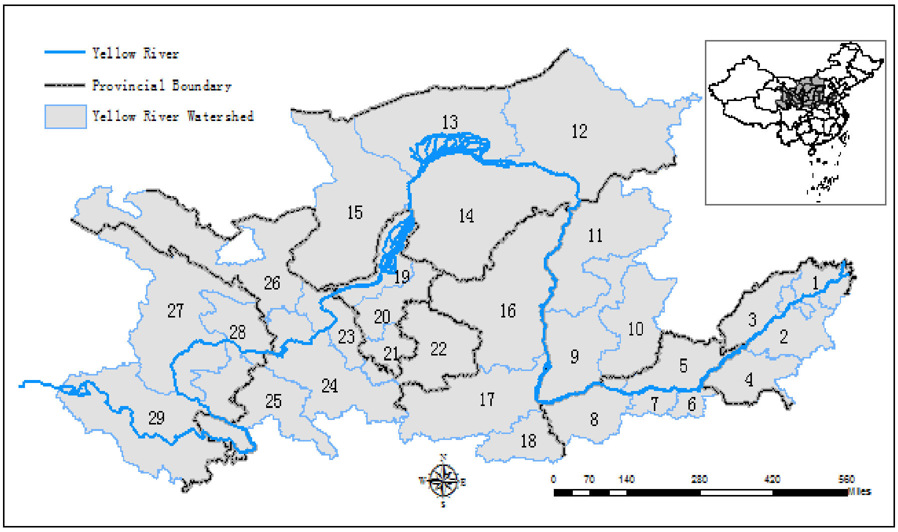
Abstract. This paper analyzed on temporal and spatial differences of the wheat water footprint in the Yellow River Basin during 1984-2013. The results showed: (1) GWF and BWF both decreased; (2) the GWF proportion rose from 25.7% to 35.7%; (3) the BWF proportion decreased from 74.1% to 64.3%; (4) the highest WPWF value occurred in the northwest of the Yellow river basin, while WPWF in the southeast was low. The research is conducive to adjust measures to local conditions by Analysis on temporal and spatial differences.

Introduction

Agriculture is a water-intensive business, accounting for approximately 70% of total water consumption [1]. Facing contradiction of water supply and demand, reasonable assessment for agriculture utility is required so as to improving water use efficiency to guarantee the food security.

In 2002, Dutch scholar Hoekstra A. Y. depicted that the cumulative virtual water content of all goods and services consumed by one individual or by the individuals of one country, called water footprint (WF). WF is a comprehensive assessment criterion that interpret both direct and indirect water consumption from consumers and producers with the information of use time, location and types of water source [2].

The majority of crop water footprint researches have been conducted from a macroscopic perspective, taken the whole world or the entire country as an object, and fruitful results are mainly contributed to water footprint quantification [3]- [5]. However, few studies attached importance to the temporal and spatial differences of WF in a specific river basin, where had unique climatic conditions and geological environment. Water issues related to wheat production in Yellow River Basin are impacted by regional climate, financial condition and infrastructural construction, which may have intimate spatial correlation. Especially Yellow River Basin with a vast territory, there is a big difference in agricultural development among its interior zones. In this paper, winter wheat in Yellow River (zone 8 province to 29 regions basic on climate and topography, Figure 1) is the main objects. The temporal and spatial differences of the water footprint of wheat is analyzed.



1.North Shandong Plain
2.Middle Shandong Hill
3.West Shandong Plain
4.Southwest Shandong Plain
5.Southwest of Shandong
6.Eastern Henan Plain
7.Middle Henan Plain
8.Mountainous Area of West Henan
9.Shanxi Basin
10.Eastern Shanxi Hill
11.Northwest Shanxi Mountain
12.Ulanqab Plateau
13.Hetao Plain
14.Ordos Plateau
15.Alxa Plateau
16.North Shaanxi Plateau
17.Central Shaanxi Plain
18.Qinling Mountain
19.Ningxia Plain
20.Arid Area in Central Ningxia
21.Guyuan Mountain
22.East Gansu Region of Loess Plateau
23.Middle Gansu Transitional Zone
24.Middle Gansu Region of Loess Plateau
25.Gannan Plateau
26.Gansu Corridor
27.Qilian Mountain
28.Huangshui Valley
29.Southern Qinghai Plateau

Fig. 1 Location of Yellow River Basin and the names of its 29 zones

Method

Green and blue water evapotranspiration during the crop growth period can be estimated with the CropWat model introduced by FAO [2]:

$$ET_{green} = \min(ET_c, P_{eff})$$
$$ET_{blue} = \max(0, ET_c - P_{eff}) \qquad (1)$$

The major factor that affects green water footprint is effective precipitation, which is retained by the soil as a potential water supply for plants. In general, effective precipitation is less than the total precipitation because crops cannot completely use all rainfall due to surface run-off or percolation.

To calculate the effective rainfall, the method of the United States Department of Agriculture–Soil Conservation Service (USDA–SCS) was selected because it is one of the most extensively used for this objective. The model calculates P_{eff} as follows [6]:

$$P_{eff} = \begin{cases} P(4.17-0.02P)/4.17, P<83mm \\ 41.7+0.01P, P\geq 83mm \end{cases} \qquad (2)$$

where P and P_{eff} are the 10-day precipitation and effective precipitation respectively in mm.

CWU is calculated from the accumulation of daily ET_c during the length of growing period.

$$\text{CWU}=10\times\sum_{d=1}^{\text{lgp}} ET_c \qquad (3)$$

The modulus of function 10 is to convert the water depth (mm) into the unit volume content ($m^3 \cdot ha^{-1}$)

In summary, green water footprint (GWF), blue water footprint (BWF) and are:

$$\text{GWF} = CWU_{green}/Y[\text{volume}/\text{mass}]$$
$$\text{BWF} = CWU_{blue}/Y[\text{volume}/\text{mass}] \qquad (4)$$
$$\text{WF=GWF+BWF}$$

Results

The paper computed wheat production water footprint (WPWF) in the Yellow River Basin in 8 provinces including 29 regions during 1984-2013.Green water footprint (GWF) and blue water footprint (BWF) of wheat represent crop absorbing effective rainfall and irrigation water respectively to growth, therefore, analyzing GWF and BWF varied with time is meaningful. Figure 2 showed that GWF generally dropped during 30 years except for a slight rose in the middle 1990s, while the proportion of GWF rose from 25.7% to 35.7% continuously meaning that wheat assimilated more GWF than BWF. On the contrary, both BWF value and BWF proportion went down undulated. BWF proportion respectively decreased from 74.1% to 64.3%. The precipitation was increasing because of global climate change, which enlarged green water resource. And the advancement of rainwater harvesting technology and water-saving technology were another wrinkle to green water proportion rising. Meanwhile, optimized irrigation schedule and sophisticated irrigation system have improved irrigation and use efficiency of blue water. Along with the social economy level of country was developing rapidly, people realized the barriers among social demand, resources and environment owing to low level of agricultural productivity. Therefore, the government has taken effective measures, for example, choosing gentle slope in appropriate soil condition to plant crops or implemented the engineering of changing mountain slop into terrace or enhanced commodity transaction between plain and basin in order to improve the yield of wheat and decrease WPWF.

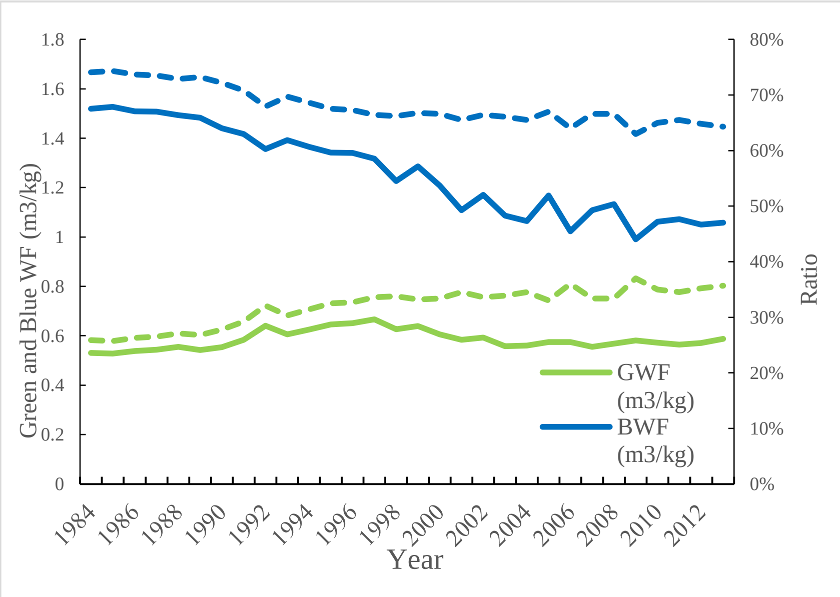


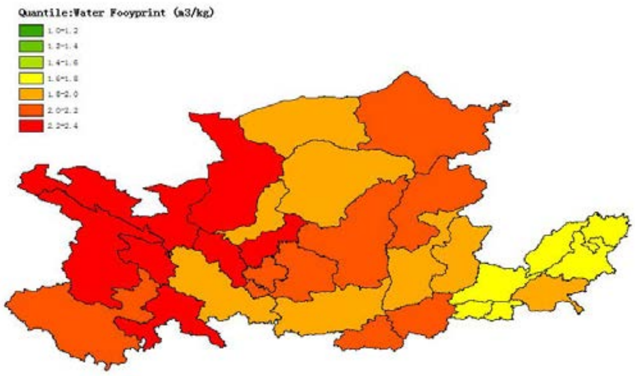
Fig. 2 Inter-annual variability of GWF and BWF mean and ratio of wheat production

Effective rainfall has direct impact on GWF. And irrigation schedule programming is determined by rainfall to some extent, thus, effective rainfall has indirect impact on BWF. Therefore, it is meaningful to study WPWF in dry year and rainy year. Compared with the average annual precipitation (421.5 mm) during 1984-2013 years when precipitation is > 10% higher were humid years, years when precipitation were > 10% lower were dry years and years when precipitation decreased or increased within 10% were average years. In terms of table 1, the proportion of GWF was the highest in wet year and the minimum in dry year.

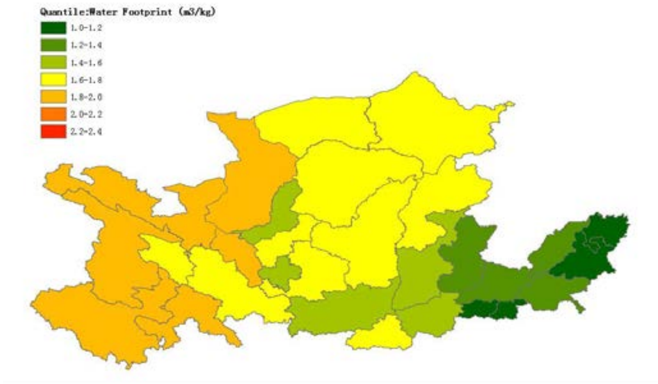
Table 1 The WPWF in the different types of rainfall years

	PR(mm)	GWF Ratio	WF(m^3/kg)
1986(dry)	351.3	26.30%	1.24
2001(humid)	540.6	33.90%	0.84
2005(average)	452.7	33.20%	0.90

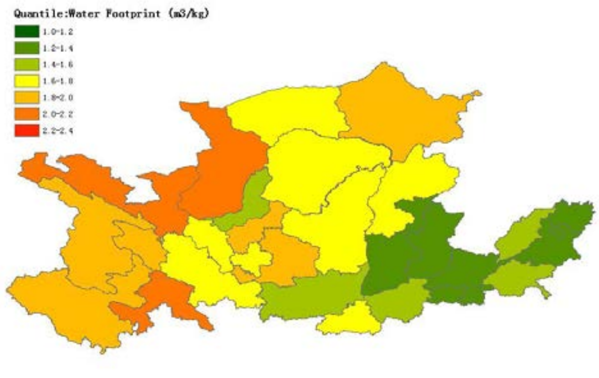
Figure 3 presents the spatial distribution of WPWF in different types of rainfall years. Agricultural production level and climate difference caused the crop yield gap, which lead to WPWF widely from region to region. In general, the highest WPWF value occurred in the northwest of the Yellow river basin, while WPWF in the southeast was low. The northwest regions, located on the upper part of Yellow river, are temperate continental climate and plateau-climate with less rainfall and large temperature difference, arising large amounts of water requirement. But on the contrary, the lower reaches of yellow river refer to southeastern regions where more water can be absorbed by crops from rainfall, given a superior agro ecological environment compared to northwest. Figure 3(a) presents that the high WPWF values were distributed in (26) Gansu Corridor and (27) Qilian Mountain in dry year1986, because of lower yields. For instance, the highest WPWF was observed in (26), where it was 2.35m^3/kg, followed by (27) with 2.28 m^3/kg. The lowest WPWF was calculated for (7) Middle Henan Plain with 1.61 m^3/kg, and (6) Eastern Henan Plain with 1.64 m^3/kg. This could be explained by the relatively higher wheat yields in these two areas. Compared to 1986, the WPWF of all areas showed an obvious decreasing trend in 2001 (Figure 3b), owing to the wetter climate. (26) also had the highest WPWF of wheat production, which was 1.98 m^3/kg, and the WPWF of (27) took second place with 1.87 m^3/kg. The lowest areas are still (6) and (7). As shown in Figure 3(c), the WPWF of all areas presented an increasing trend in 2005, compared to 2001. (15) Alxa Plateau had replaced (27) as the county with the second highest WPWF, which was 2.15 m^3/kg. The value of (26) 2.19 m^3/kg, which also ranked first. The lowest WPWF values were located in (7) and (6), which were 1.08 m^3/kg and 1.12 m^3/kg, respectively.



(a)



(b)



(c)

Fig. 3 The spatial distribution of WPWF in the different types of rainfall years

Summary

This paper analyzed on temporal and spatial differences of the wheat water footprint in the Yellow River Basin during 1984-2013. GWF and BWF both decreased. the proportion of GWF rose from 25.7% to 35.7% while the BWF proportion decreased from 74.1% to 64.3%. Agricultural production level and climate difference caused the crop yield gap, which lead to WPWF widely from region to region. In general, the highest WPWF value occurred in the northwest of the Yellow

river basin, while WPWF in the southeast was low. The agricultural planting in the Yellow River Basin will take full advantage of Yellow River water resources and make the best of storage facility to decrease the crop water footprint. It is necessary to optimized crop planting scale and continue to strengthen agricultural input. It is worthy to spread the intensive production.

References

[1] D. Molden, T. Y. Oweis, S. Pasquale, Pathways for increasing agricultural water productivity, Water for Food, Water for Life, a Comprehensive Assessment of Water Management in Agriculture, London and Colombo: Earthscan, 2007.

[2] A. Y. Hoekstra, A. K. Chapagain, M. M. Aldaya, et al, The Water Footprint Assessment Manual: Setting the Global Standard, London: Earthscan, 2011.

[3] C. Zhao, B. Chen, T. Hayat, A. Alsaedi, B. Ahmad, Driving force analysis of water footprint change based on extended STIRPAT model: Evidence from the Chinese agricultural sector, Ecol. Indic., 2014, 47:43-49.

[4] Y. Zhang, Q. Yang, Decoupling agricultural water consumption and environmental impact from crop production based on the water footprint method: A case study for the Heilongjiang land reclamation area, China, Ecol. Indic., 2014, 43(43):29-35.

[5] X. C. Cao, P. T. Wu, Y. B. Wang, X. N. Zhao, Water Footprint of Grain Product in Irrigated Farmland of China, Water Resour. Manag., 2014, 28(8):2213-2227.

[6] FAO, CropWat 8.0, land and water development division, Food and Agriculture Organization of the United Nations, Rome, 2009