A Regional Scale Crop Water Footprint Quantification Method Based on SWAT-MODFLOW Model

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Background

●Water footprint can reflect the type of water source, the amount of water, the efficiency of water use and the impact on the ecological environment in the process of agricultural production. Comprehensive and accurate quantification of crop water footprint is a prerequisite for scientific and rational evaluation and management of agricultural water and efficient utilization of water resources. At present, there are two methods for calculating crop water footprint: 1)field scale method only calculates water consumption of crops on the field, which is only suitable for evaluating field water use; 2)The regional scale method considers the loss of crop production from the whole region, including water transport and drainage, but lacks the quantification of crop use of shallow groundwater.

●In view of the lack of crop water footprint quantification methods including crop utilization of surface water and groundwater in shallow groundwater buried areas, a SWAT-MODFLOW coupling model was established in Hetao irrigation district of Inner Mongolia, China, to simulate the hydrological cycle process of agricultural production in the irrigation area, and to analyze the utilization of surface water and groundwater during crop growth. Combined with the water footprint theory, a SWAT-MODFLOW model based on regional scale crop water footprint quantification method was established to analyze the spatial changes of crop water footprint in Hetao irrigation district, providing theoretical support for regional agricultural water resources utilization, evaluation and management.

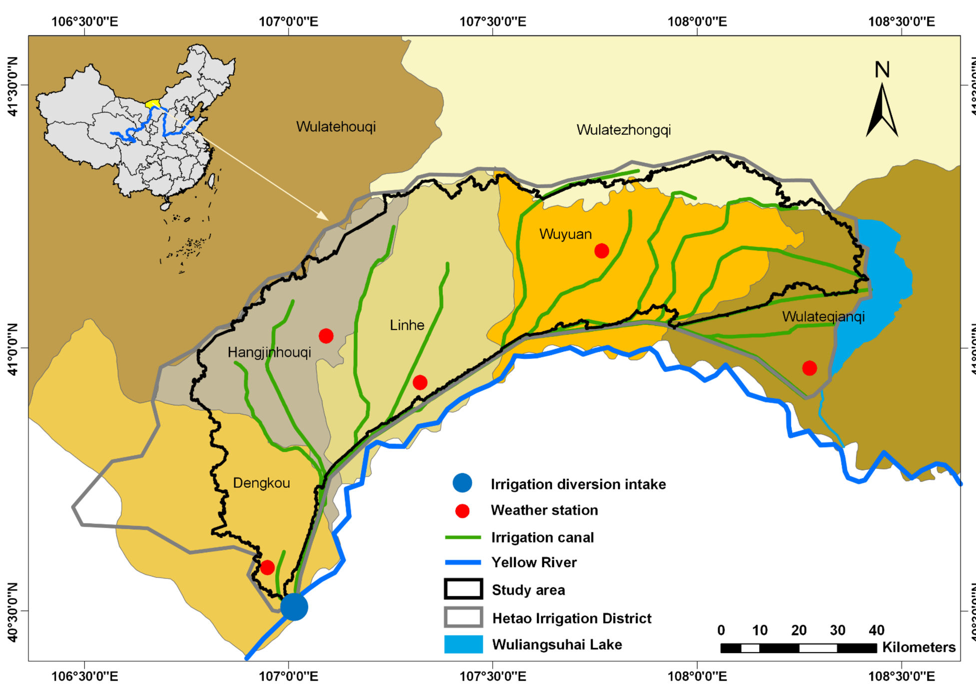

Fig.1 Map of Hetao irrigation district

Methods

●Hetao irrigation district is one of the three largest irrigation district in China, with a land area of 1.12×10^4 km^2, of which 61% is cultivated land. The average annual precipitation is 180mm and the average annual potential evaporation is 2200mm. The irrigation water in the irrigation area originates from the Yellow River, with 780km of main irrigation canals and 750km of main drainage ditches (Fig.1). Agriculture includes rain-fed agriculture and irrigation agriculture (Fig.2), Hetao irrigation district is a typical irrigated agriculture. In irrigated areas, the water output of farmland is mainly evapotranspiration and drainage, while the water input mainly comes from irrigation, precipitation and part of groundwater. Non-farmland land cannot meet the growth of natural vegetation due to natural precipitation, and will use groundwater from farmland irrigation seepage(Fig.3).

●This study expanded the source of blue water in crop water footprint (Fig.4). On the scale of irrigation area, crop growth water consumption includes channel water loss, field drainage, evapotranspiration and direct utilization of groundwater in shallow groundwater areas. In this study, quantification of crop utilization of shallow groundwater was added.

●Calculation process (Fig.5) : first, SWAT model and MODFLOW model are constructed respectively in the study area, and the SWAT-MODFLOW coupling model is constructed based on the mutual feed relationship of variables between the two minimum computing units. Finally, parameter calibration and model verification are carried out for the coupling model. Set different crop water use scenarios (scenario 1 irrigation, scenario 2 no irrigation), analyze various water consumption conditions during crop growth, and calculate the regional crop production water footprint combined with crop yield. The calculation method is as follows equation.

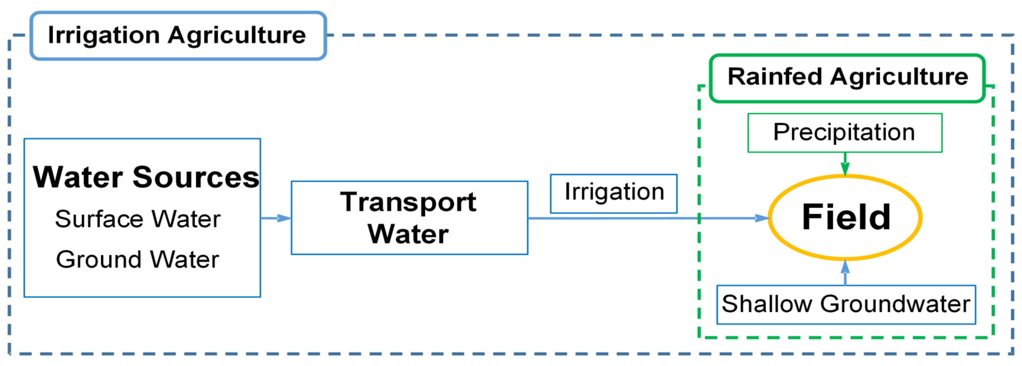

Fig.2 Two models of water use in agricultural production

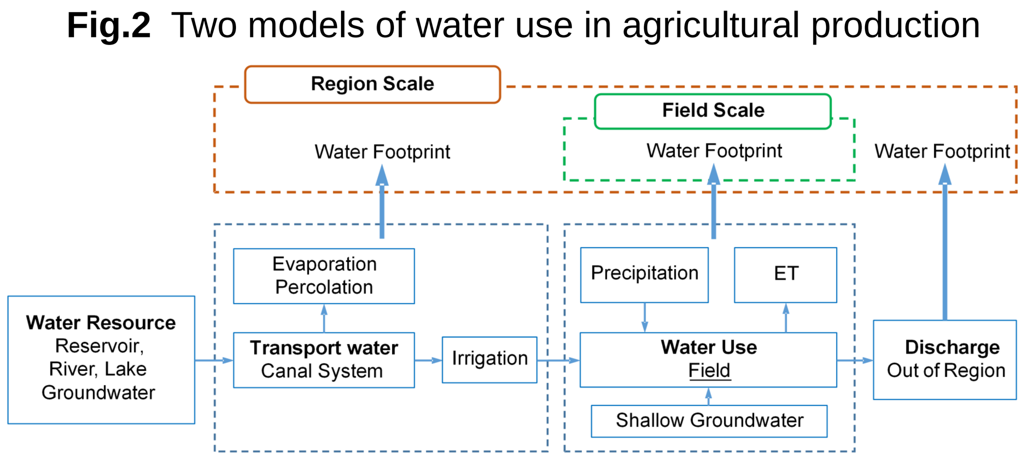

Fig.3 Two scales of crop water footprint

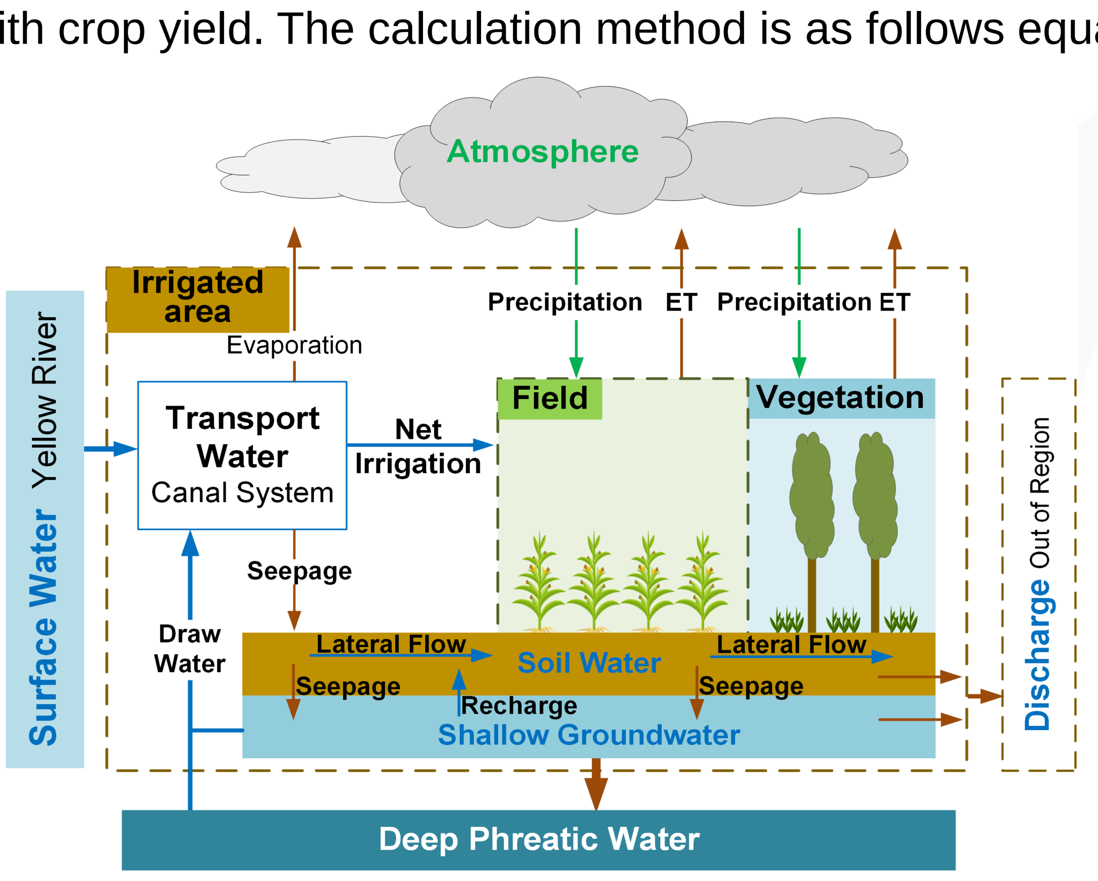

Fig.4 Analysis of agricultural water use process in Hetao irrigation district

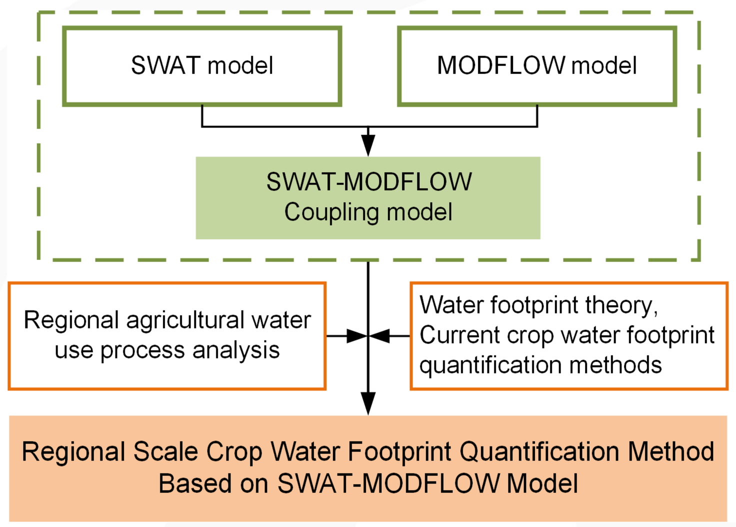

Fig.5 Calculation process

$$\begin{cases} WF = WF_{green} + WF_{blue} = \frac{W_{green}}{Y} + \frac{W_{blue}}{Y} \\ W_{green} = Q_p \\ W_{blue} = Q_i + Q_g + Q_d \end{cases}$$

$$Q_p = \frac{ET_{s2} - Q_{g2}}{S} = \frac{\sum (ET_{s2} - REVAP_{s2}) \times AREA}{\sum AREA}$$

$$Q_i = ET_{s1} - Q_p = \frac{\sum (ET_{S1} \times AREA)}{\sum AREA} - Q_P$$

$$Q_g = \frac{\sum PERC_{s1} \times AREA}{\sum AREA}$$

$$Q_d = \frac{\sum WYLD \times AREA}{\sum AREA}$$

Note: In the formula, Y is the crop yield per unit area, kg; Parameters such as ET, REVAP, AREA, IRR, and WYLD are derived from the SWAT-MODFLOW coupling model.

Results

●Fig. 6 is the water circulation process of Hetao irrigation district. The main water source in Hetao is 3.52 billion m^3 of irrigation water, followed by 1.17 billion m^3 of precipitation, accounting for 71.9% and 23.9% of the total water resources in Hetao, respectively. The water sources in non-agricultural land are mainly precipitation and shallow groundwater. The main water consumption in the irrigation area was 3.67 billion m3, accounting for 77.8% of the total water resources consumption. Farmland ET is the main part of ET in Hetao, accounting for 73.3% of the total ET. The non-agricultural land ET is greater than precipitation, so vegetation needs to absorb shallow groundwater.

●Fig. 7 shows the spatial distribution of water footprint of three crops in Hetao irrigation district. The water footprint of the three crops is very different, among which the water footprint of sunflower is the largest, followed by wheat, and corn is the smallest. In addition, the blue water footprint of wheat, corn and sunflower accounted for 89%, 87% and 86% of the total crop water footprint, respectively. The spatial distribution of water footprint of the three crops decreased from east to west, and it was lower in the central region, and the regional distribution of each crop was different.

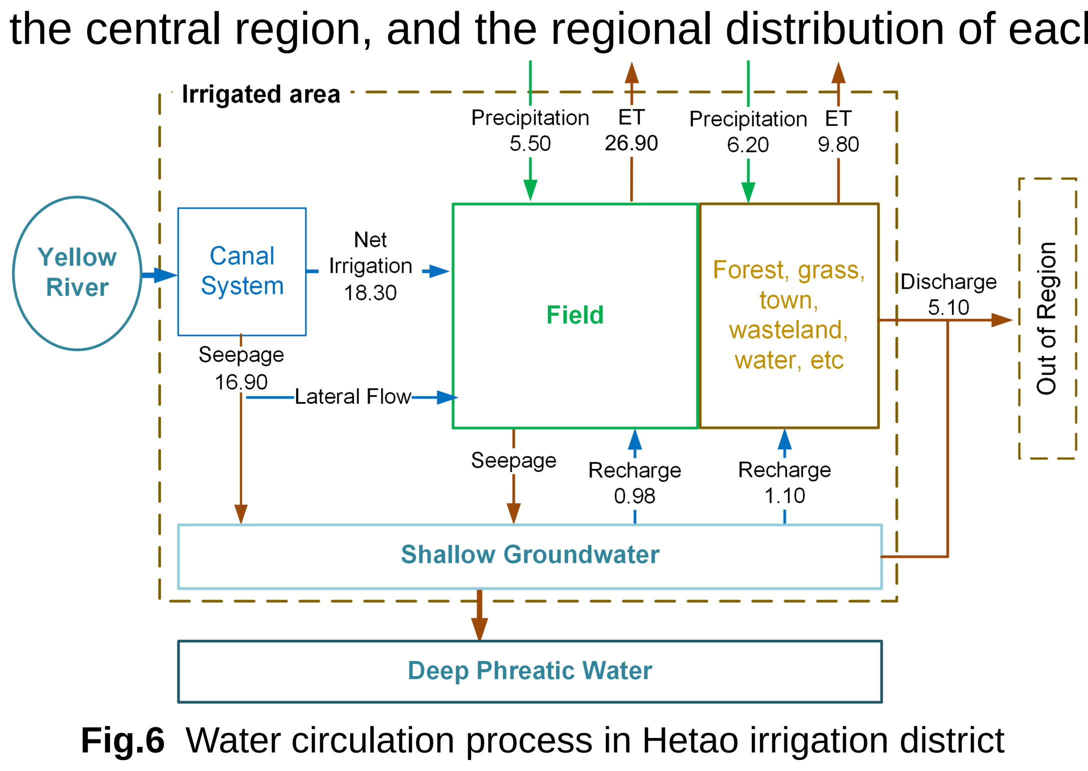

Fig.6 Water circulation process in Hetao irrigation district

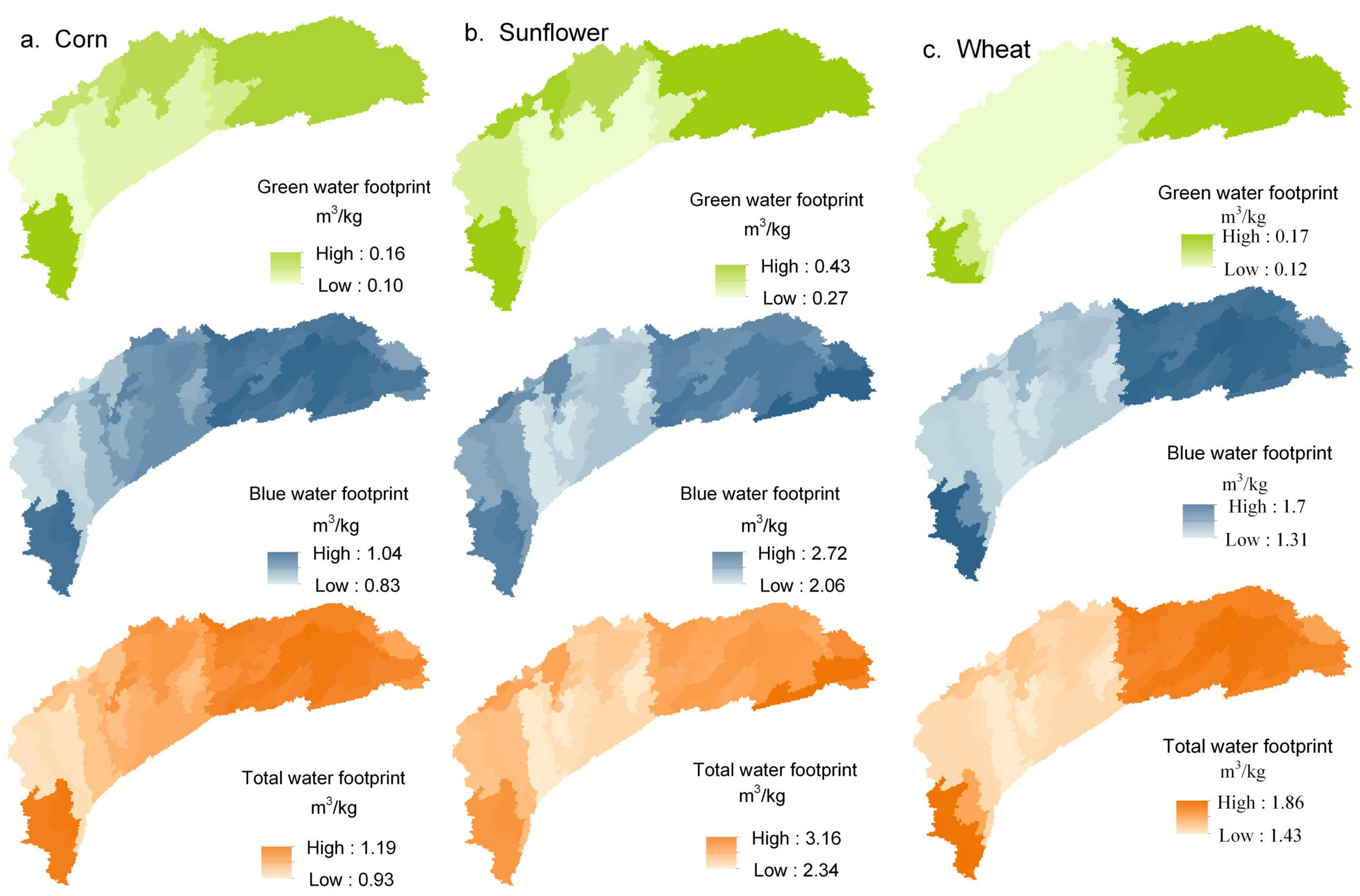

Fig.7 Spatial distribution of crop water footprint of wheat, maize and sunflower

Conclusions

●In shallow groundwater buried areas, considering the direct utilization of groundwater by crops, a SWAT-MODFLOW coupling model was established to analyze the hydrological cycle process of irrigated areas, analyze the hydrological factors related to agricultural production, and construct a regional scale crop production water footprint quantization method based on SWAT-MODFLOW, it is found that: 1) This method can comprehensively simulate crop water use process in shallow groundwater area and quantify crop water footprint, which is an extension and improvement of crop water footprint quantification method; 2) The water circulation in the Hetao is mainly vertical, and the horizontal movement of groundwater is relatively small through ET, irrigation and precipitation supplement, and irrigation leakage plays an important role in maintaining the ecological environment of the irrigation area; 3) The water footprint hotspots of three crops were found in Hetao, which was helpful to improve the water resource management capacity of irrigation district.

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