Whether indirect water could be ignored in the virtual water content of agricultural production?

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Abstract. The study of virtual water content (VWC) of crops can provide a basis for agricultural water resources management and a way to improve agricultural water use efficiency. The existing calculation methods on VWC of crops only considered the direct water use of agricultural production while ignoring the indirect water use of agricultural production. The use of essential inputs for agricultural production including chemical fertilizers, pesticide, and agricultural machinery power are bound to bring indirect water for VWC of agriculture production. We calculated the indirect water of strawberry in Inner Mongolia based on the Input-Output method, to study whether indirect water could be ignored in the VWC of agricultural production.

1. Introduction

The term ‘virtual water’ was first coined by Allan in 1994 [1]. The concept of virtual water provides another perspective for water resources management [2]. The VWC of a crop is the amount of fresh water consumed and affected by pollution during crop production. It consists of three components: 1) green water, precipitation consumed during crop production; 2) blue water, surface or underground water consumption during crop production; 3) grey water, the amount of fresh water needed to digest pollutants during crop production [3, 4]. Some studies have focused on developing the concept of water footprints and quantifying the water footprints of various products from a global or national consumption perspective [4, 5].

However, most of these studies only considered the direct water, without considering the indirect water. Chemical fertilizers, pesticide, agricultural machinery power and so on are essential inputs for agricultural production. The use of these agricultural inputs for agricultural production is bound to bring indirect water [6]. Zhang et al. used IO method to calculate the virtual water contribution to the sector of agriculture by other sectors [6].

In this paper, we would calculate the indirect VWC and total VWC use of strawberry of Inner Mongolia in 2007 to determine the proportion of indirect water in the total water use. Thus, we would investigate whether the indirect water could be ignored in the actual virtual water use of agricultural production.

2. Methodology and data

2.1. Methodology
Direct green water, direct blue water and indirect water were considered to reflect the water consumption in crop production.

The input-output model is used to calculate the indirect virtual water amount of crops provided by each sector [6]. The calculation methods are as follows:

(1) Direct consumption coefficient matrix calculation

The input-output table is used primarily because it reflects the exposure of the material and technical. This relation is mainly reflected by the direct consumption coefficient.

\[ A = \begin{vmatrix} a_{ij} \end{vmatrix} = \begin{vmatrix} x_{ij} \end{vmatrix} / x_i \]  

where \( A \) is the direct consumption matrix, \( a_{ij} \) the direct consumption coefficient, \( x_{ij} \) the monetary volume of products from sector \( j \) consumed by sector \( i \) in its productive progress (RMB), \( x_i \) the output of sector \( i \) (RMB).

(2) Complete consumption coefficient matrix calculation

Compared with the direct water coefficient, the complete consumption coefficient provides a more accurate measure of the pressure on water resources from expanded production in the productive sector.

\[ B = \begin{vmatrix} b_{ij} \end{vmatrix} = (I - A)^{-1} - I \]  

where \( B \) is the complete consumption coefficient matrix, \( b_{ij} \) the complete consumption coefficient.

(3) Water use coefficient calculation

In order to calculate indirect water use, it is necessary to calculate the water consumption coefficients for different sectors, that is, the amount of water required to produce a monetary unit (RMB). The equation for calculating the water factor vector is as follows:

\[ DWC_i = w_i / x_i \]  

where \( DWC_i \) is the direct water coefficient of sector \( i \) (m³ RMB⁻¹), \( w_i \) the direct water consumption of sector \( i \) (m³), \( DWC_i \) the amount of direct water intake to produce one monetary unit of production.

(4) Indirect water of agriculture calculation

Indirect water of agriculture is the amount of total water input by other sectors.

\[ VW_{\text{blue,indirect}}^a = \sum_i (DWC_i \times b_{ia}) \times c_a \]  

where \( VW_{\text{blue,indirect}}^a \) is the indirect water consumption of agriculture (m³), \( b_{ia} \) the complete consumption coefficient of sector \( i \) for agriculture, \( c_a \) the total consumption of agriculture (RMB).

(5) Indirect water of crops calculation

\[ VW_{\text{indirect}}^c_i \] is calculated according to the proportion of indirect water use of crop \( i \) among the total indirect water consumption of agriculture.

\[ VW_{\text{indirect}}^c_i = \frac{VW_{\text{indirect}}^a \beta_i}{A_i \times Y} \]  

where \( \beta_i \) is the proportion of indirect water use of crop \( i \) among the total indirect water consumption. \( \beta_i \) can be calculated as follows:

\[ \beta_i = \frac{PC_i \times A_i}{\sum_{i=1}^{n} (PC_i \times A_i)} \]  

where \( PC_i \) is the planting cost of crop \( i \) per unit area (RMB ha⁻¹).

The direct green water of crop is the minimum of the potential crop evapotranspiration and the effective precipitation [2]. The direct blue water of crop is calculated based on the actual irrigation water consumption [7]. Due to the lack of data of pesticide and chemical fertilizer used in strawberry cultivation, the direct grey VWC of strawberry in Inner Mongolia can not be calculated.

2.2. Data

The climatic data of Inner Mongolia in 2007, including monthly average maximum temperature, monthly average minimum temperature, relative humidity, wind speed, precipitation and sunshine hours, were all taken from the China Meteorological Administration, National Climate Center [8]. Agricultural data including strawberry yield and sown area were taken from China Agricultural Yearbook [9]. Irrigation water consumption and irrigation water supply data were taken from China Water Resources Bulletin 2007 [10]. Water data of various sectors were taken from the Inner Mongolia
Statistical Yearbook 2008. The IO data of Inner Mongolia were come from the Inner Mongolia official IO table 2007.

3. Results and Discussions
The indirect water of VWC of crops is the indirect water investment by other sectors for crops. Chemical fertilizers, pesticide, agricultural machinery power and so on, these are essential inputs for agricultural production. The use of these agricultural inputs for agricultural productions is bound to bring indirect water to VWC of crops. Shown in Fig. 1, the direct green, direct blue, indirect water and total VWC of strawberry of Inner Mongolia in 2007 was 0.023 m$^3$ kg$^{-1}$, 0.035 m$^3$ kg$^{-1}$, 0.035 m$^3$ kg$^{-1}$ and 0.093 m$^3$ kg$^{-1}$ respectively. The proportion of the direct green, direct blue and indirect water of VWC accounted for the total VWC of strawberry was 24.7%, 37.6% and 37.6%. The indirect water VWC of strawberry was larger than the green water VWC and the same as the blue VWC. Indirect water was the most important part of the total water.

![Virtual Water Content of Strawberry](image)

Figure 1. The VWC of strawberry (m$^3$ kg$^{-1}$).

Gray water was ignored in the calculation of the total VWC of Inner Mongolia, so the ratio of other parts of the total VWC to the total VWC was artificially increased. The proportion of direct grey water VWC in the total VWC of rice, wheat and corn was 42.3%-59.1% in Inner Mongolia. In this study, if the direct grey water in the total VWC of strawberry in Inner Mongolia was 60%, the indirect VWC of strawberry in Inner Mongolia was 23.5% of the total VWC. Indirect VWC of strawberry was still an important part of the total VWC, can not be ignored.

4. Conclusion
Based on the research of Zhang et al., the indirect VWC of rice is relatively small in each region and only a small fraction of the total VWC [6]. Therefore, the indirect water consumption can be neglected when calculating the total VWC of rice in different regions of China [6]. However, from the calculation of the VWC of strawberry in Inner Mongolia, it can be found that the indirect VWC of agriculture production with large economic inputs can not be ignored in the regions with less effective rainfall and limited water consumption for irrigation. The indirect VWC of agriculture production such as strawberry, watermelon and melon grown in regions such as Inner Mongolia, Xinjiang, Ningxia and Beijing can not be ignored when calculate the VWC.

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