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Analysis

The blue, green and grey water footprint of rice from production and consumption perspectives

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ABSTRACT

The paper makes a global assessment of the green, blue and grey water footprint of rice, using a higher spatial resolution and local data on actual irrigation. The national water footprint of rice production and consumption is estimated using international trade and domestic production data. The global water footprint of rice production is 784 km^3/year with an average of 1325 m^3/t which is 48% green, 44% blue, and 8% grey. There is also 1025 m^3/t of percolation in rice production. The ratio of green to blue water varies greatly over time and space. In India, Indonesia, Vietnam, Thailand, Myanmar and the Philippines, the green water fraction is substantially larger than the blue one, whereas in the USA and Pakistan the blue water footprint is 4 times more than the green component. The virtual water flows related to international rice trade was 31 km^3/year. The consumption of rice products in the EU27 is responsible for the annual evaporation of 2279 Mm^3 of water and polluted return flows of 178 Mm^3 around the globe, mainly in India, Thailand, the USA and Pakistan. The water footprint of rice consumption creates relatively low stress on the water resources in India compared to that in the USA and Pakistan.

1. Introduction

Rice is one of the major crops feeding the world population and is most important ingredient in food composition in South Asia and Africa. Large irrigation projects are often constructed to meet the water demand in rice production. As a result, rice is one of the largest water consumers in the world. This paper quantifies how much fresh water is being used to produce rice globally, distinguishing between two different sources: irrigation water withdrawn from ground- or surface water (blue water) and rainwater (green water). It also quantifies the volume of polluted water related to the use of nitrogen fertilisers in rice production (grey water).

Rainwater and irrigation water are necessary for rice growth in two ways: to maintain soil moisture and – in wet irrigation – to maintain the standing layer of water over the paddy field. In the major rice-producing regions of the world, the crop is grown during the wet (monsoon) season, which reduces the irrigation demand by effectively using rainwater.

As much of the standing water in paddy fields percolates and recharges groundwater and surface water, there is a substantial contribution to the local blue water availability. Percolation can be seen as a loss to the paddy field, but for the catchment area it is not considered as a loss, because the water can be captured and reused downstream (Bouman et al., 2007b). In some irrigation systems in flood plains with impeded drainage or systems in low lying deltas a continuous percolation can even create shallow ground water tables closer to the surface (Belder et al., 2004). Although the paper focuses on the estimation of evapotranspiration from rice fields, it also estimates percolation flows, because evapotranspiration and percolation are both part of the soil water balance.

2. Method and Data

There are mainly two systems of rice production: wetland systems and upland systems. About 85% of the rice harvest area in the world is derived from wetland systems (Bouman et al., 2007b). About 75% of rice production is obtained from irrigated wetland rice (Bouman et al., 2007b). In Asia, rice fields are prepared by tillage followed by puddling. The soil layer is saturated and there is standing water during the entire growth period of the crop. In the USA, Australia, parts of Europe and some Asian countries, rice land is prepared dry and flooded later.

During the period of 2000–2004, the average annual global production of rice was 592 million metric tons with an average yield of 4.49 t per hectare. In the production database of the FAOSTAT data (2006), 115 countries are reported as rice producers. Table 5 presents the list of top 33 largest rice producers accounting for more than 98% of the global rice production. During the period 2000–2004, the global rice production came mainly from China (30.0%), India (21.4%), Indonesia (8.8%), Bangladesh (6.3%), Vietnam (5.7%), Thailand (4.5%), Myanmar (3.8%), Philippines (2.3%), Brazil (1.9%), Japan (1.9%), USA (1.6%), Pakistan (1.2%), and Korea R (1.2%). These

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13 countries together account for more than 90% of the global rice production. They account for more than 82% of the total export of rice-equivalent globally. About 6–7% of the world rice production is traded internationally.

The paper is based on data retrieved from variety of sources. It is inevitable that any errors in these sources can influence the result of this analysis. We have cross checked these data sources with other independent sources and found them to be consistent enough for this analysis.

2.1. Crop Water Use

The reference crop evapotranspiration (ET_o) and monthly average rainfall data for the concerned climate stations are taken from the CLIMWAT database (FAO, 1993) for all countries, but from FAOCLIM (FAO, 2001) for the USA. The ET_o data in these databases are derived using the Penman–Monteith equation as described (Allen et al., 1998). Using the CROPWAT model (FAO, 1992), the crop evapotranspiration (ET_c) and the available effective rainfall are calculated for the given set of data on ET_o, monthly rainfall, K_c and the crop calendar. Rice crop coefficients are taken from (Allen et al., 1998). Monthly data on rainfall and ET_o are distributed within the month to obtain data per 5 days. CropWat for Windows does this in two steps; first the rainfall from month to month is smoothed into a continuous curve. The default curve is a polynomial curve. In some cases when a smooth curve is difficult to fit then a linear interpolation between monthly values is made. Next, it is assumed that there are a given number of individual rainstorms in a month based on assumption that it is unlikely that the rain will fall at a continuous uniform intensity throughout each month (Clarke et al., 1998). We have selected the default value in CropWat model, which is one rainstorm in every 5 days period. As CROPWAT 4 (FAO, 1992) is not suitable to calculate the crop water requirement for rice (Clarke et al., 1998), we have used it only to get the values of ET_c and the available effective rainfall for a time step of 5 days. For each of the 13 countries, the crop evaporative demand (ET_c) is calculated for each season of rice production in all the regions. Data on the major crop season for each harvesting regions in each of these 13 countries, regional share of production (%) to the total national production and irrigation coverage per region, the crop planting date, crop length in days and relevant climate stations are taken from various sources (USDA, 1994; Directorate of Rice Development, 2001). We have used the USDA SCS (United States Department of Agriculture Soil Conservation Service) method to estimate the effective rainfall in CROPWAT model.

For rice cultivation in wetland systems, paddy fields are prepared and the soil is kept saturated. The common practice is to first prepare land by puddling. This is done by saturating the soil layer for 1 month prior to sowing. The volume of water (SAT) necessary for this stage is assumed to be 200 mm as suggested by Brouwer and Heibloem (1986). As lowland rice is grown in a standing layer of water, there is a constant percolation and seepage loss during this period. Percolation loss (PERC) is primarily a function of soil texture. It varies from 2 mm/day (heavy clay) to 6 mm/day for sandy soil. As rice is mostly grown in soil with more clayey texture, for the present study we have taken 2.5 mm/day as an average (Brouwer and Heibloem, 1986) for the entire period of rice cultivation except for the last 15 days when the field is left to dry out for easy harvesting. A water layer is established during transplanting or sowing and maintained throughout the growing season. Although the volume of water needed for maintaining the water layer (WL) is available for percolation losses and to meet the evaporative demand of the crop during the last phase of paddy growth, it is necessary to get this volume of water at the beginning of the crop period (Fig. 1). In this study, it is assumed that a water layer of 100 mm is established in the month of sowing. A time step of 5 days is chosen for the calculation. The total water demand (WD) is calculated by adding ET_c, WL, SAT and PERC for each time step.

For the last 15 days prior to the harvesting when the land is left to dry out, the volume of water required for evaporation is supplied by the effective rainfall in the period and any residual soil moisture maintained from the previous stages. Approximately 30 days before the land is left to dry out, the standing layer of water is slowly left to deplete without any augmenting water supply to maintain the water layer. This practice makes the best use of water supplied to maintain the WL in the previous stages. The method, thus, accounts the storage of water in time either as soil moisture or as water layer over the rice field.

Any residual soil moisture after the harvest is not included in the water footprint estimation. It is assumed that the initial soil moisture before the land preparation is negligible. It is also assumed that the contribution of capillary rise from the shallow ground water table in the rice fields is negligible. The net inflow and outflow of the overland runoff from the bunded rice fields are assumed to be zero as well. The schema to measure the depth of water available (WA) for use in different stages of crop development is presented in Fig. 2.

The water use in the rice fields is calculated for each 5-day cumulative period using the schema as presented in Fig. 3. If the total water demand WD is less than total water available WA, green water use is equal to the demand WD. In cases where the WD outstrips WA, the deficit is met by irrigation water supply. This deficit is called irrigation water demand. If a paddy field is 100% irrigated, it is assumed that the 'blue water' use in crop production is equal to the deficit. For areas equipped with partial irrigation coverage, the blue water use is estimated on a pro-rata basis.

In order to show the sort of detail we have applied, we give an example here for India. There are two major rice production seasons in India, known as Kharif (monsoon season) and Rabi (dry season). For the period of 2000–2004, the share of Kharif production to the gross national production is 86% and the remaining 14% is from Rabi. The data for harvested area, crop period, irrigated share, crop yield and total production are taken from the Directorate of Rice Development (2001). Crop water use depends on the crop calendar adopted and it is difficult to analyse multiple crop calendars that possibly exist in a region. The study assumes a single representative calendar is valid per region in India. The planting and harvesting time for the crop are assumed to be at the average of these dates gathered from various sources such as the Directorate of Rice Development (2001), IRRI (2006), and Maclean et al. (2002). The major Kharif rice-producing regions in India are Uttar Pradesh, West Bengal, Punjab, Bihar, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Orissa and Assam, producing 85% of the national Kharif rice production. The major Rabi rice-producing regions are Andhra Pradesh, West Bengal, Tamil Nadu, Karnataka and Orissa, producing 92% of the national Rabi rice production. The state-wise data for irrigated area are taken from the (Directorate of Rice Development, 2001). The rice production in Rabi is assumed to be fully irrigated and the remainder of the total irrigated area is attributed to the Kharif rice. The irrigation water requirement (m^3/ha) and the green water use (m^3/ha) are calculated per state for the major rice-producing regions. For the remaining regions, the average irrigation water requirement and green water use are calculated based on the data for the major regions. Blue water use is calculated by multiplying the irrigation requirement with the irrigated area in each season per state. The green water use in irrigated areas is calculated by multiplying the green water use (m^3/ha) by the total area in each season.

The example of India is followed for each of the other 12 countries. The planting and harvesting dates for all of the crop producing regions in these countries are chosen based on the major crop season in these regions (USDA, 1994; Directorate of Rice Development, 2001). For each production region, we have estimated the green water use, irrigation demand and blue water use based on whether it is a 'wetland system' or an 'upland system'. The national averages of green and blue water use are calculated based on the data per region and the share of production of each region to the total national production.