The Role of Depleting Groundwater in Global Food Production

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Abstract

Globally, a significant fraction of food production derives from groundwater in irrigated agriculture. Addressing depleting groundwater, a major threat to food security and sustainability, requires a well-informed policy debate. We present a novel methodological framework combining spatially explicit groundwater abstraction data with global food production data. This framework allows us to estimate groundwater abstraction rates beyond its natural replenishment. This groundwater depletion potentially also impacts food production and global food security as previous studies have shown. The present work assesses for the first time a global estimate of the contribution of depleting groundwater to global food production. Based on an integrated GIS analysis, we find that depleting groundwater is a significant input to global food production, and between 1.8 and 2.2 percent of total food production. The methodology was tested for the South Asia and East Asia regions as demonstrating Crop-Wise; it is found that white cereals and sugar crops exhaust most groundwater; crop groups like roots and tubers, rice, and non-food crops (mostly cumin, leguminous, and vegetables) and fruits are disproportionately grown by depleting groundwater. The results imply the critical importance of analyzing and developing congruent policies at multiple levels that account for the nexus between groundwater and food security.

Methodology

We used four global distributed datasets for our analysis: 1. Spatial Production Allocation Model (SPAM) 3 arc min, spatial resolution from 2005 on cultivated area, harvested area and crop production (wet weight) for 42 crops for irrigated and various rainfed cultivation forms (high inputs, low inputs and subsistence production) (Anderson et al., 2014, HarvestChoice 2000); 2. Food and Agriculture Organization of the United Nations (FAO) 5 arc min, spatial resolution data from 2005 on area equipped for irrigation and percentage of the area irrigated for groundwater irrigation (FAO et al., 2010); 3. PCHRater Global Water Balance (PCHRATER-GWBA, Wada et al., 2012) 30 arc min, spatial resolution model results from 1960-2000 on groundwater abstraction and groundwater depletion, the latter determined through 10,000 realizations of Monte Carlo runs to capture range of uncertainty (unpublished); and 4. Agriculture water demand and total water demand. The methodology, which provides global monthly water withdrawals for agriculture and total water demand, were provided by Utrecht University.

The methodology combined these datasets in a spatial (GIS-based) analysis to estimate the share of groundwater abstraction that was derived from groundwater abstraction and groundwater depletions. Groundwater depletion in this context is defined as the case when groundwater abstraction is greater than groundwater recharge, including return flows.

The data analysis process consisted of the following nine sequential steps (Figure 1): 1. The SPAM dataset was processed to aggregate the three rainfed categories (high, medium and low intensity) into one rainfed category, in terms of cultivated area, harvested area and production. 2. The SPAM irrigated dataset (cultivated area, harvested area and crop production) was further disaggregated and attributed to groundwater-irrigated and surface water-irrigated parts (assumming only two types of irrigation water sources) by comparing the SPAM total irrigation area and the FAO map of area irrigated by groundwater and using a set of logical decision rules. If the FAO map area replaced by groundwater runoffs then cell is classified as groundwater-irrigated area. and if the SPAM cell area is classified as groundwater-irrigated area then it is assumed that the surplus area in SPAM is surface water irrigated. If the irrigated area is less than or equal to the FAO (or GIS) area used for irrigation, then the remaining area is assumed to be non-irrigated. Conversely, if there is no groundwater-irrigated area shown in the FAO, it is assumed that the irrigation is from surface water. In this way, the final total groundwater-irrigated area and as well as the total irrigated area never exceeds the FAO-estimated area for irrigation.3. Fraction of groundwater abstraction area to total irrigated area was estimated and applied to estimate the fraction of irrigation of groundwater-irrigated area and irrigated harvestable attribuine to groundwater irrigation for the 42 crops (Step 6).

7. The harvested area and crop production attributable to groundwater depletion were derived from the total groundwater-irrigated area and harvested area (Step 6), using the fraction of groundwater depletion to abstraction (always less than 100%) (Step 5).

8. The data for the 42 crops in terms of cultivated area, harvested area, and crop production (also disaggregated into the three rainfed categories) from global food production (SPAM) and groundwater-irrigated, and groundwater irrigated and depleted) were aggregated into nine major crop groups, of which one was dedicated to irrigated crops and the other eight being rainfed crops (Step 7).

In terms of crop distribution of food production from global food production, Table 3 shows that cereals and sugar crops are the most affected, followed by roots and tubers, and vegetables. Certain crops are affected in some regions and not in others. For example, rice is more affected in Africa. The results indicate that a high proportion of all global food production is from groundwater (14.2, 9.8, 9.1, and 7.8%, respectively, as compared to an overall average of 6.7% for all crops. This is consistent with what is found in the literature, where the high market value of most of these crops, in conjunction with groundwater providing reliable irrigation water supply (Shah, 2007).

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References