Water Footprint of Food Production

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Contributor: Mesfin M. Mekonnen , Winnie Gerbens-Leenes

Blue water footprint - the volume of fresh surface and groundwater that has been evaporated or incorporated into a product.
Green water footprint - the rainwater that is stored in the root zone of the soil and evapotranspired or incorporated into the product.
Unsustainable blue water footprint - when it exceeds the available renewable blue water, thereby violating the environmental flow standard and depleting groundwater
Water footprint - an indicator of the direct and indirect water use to produce the goods and services we use.

sustainable diet, food waste, food production

1. Introduction

Agriculture is by far the largest user of water. Agricultural production needs to increase by almost 50% by 2050 compared to 2012 to meet the rising demand for food, fiber, and biofuels. This is probably going to require more water. Most of the increase in agricultural production is expected to occur in Sub-Saharan Africa and South Asia, where the agricultural output will need to more than double by 2050[1]. The expected increase in the rest of the world is around 30%. Agricultural production has increased by 260% between 1961 and 2018[2]. During the same period, the harvested crop area increased by 47%, suggesting that 113% of the increase in production is linked to an increase in crop yield. The increase in crop yield between 1961 and 1990 was 72%, but between 1991 and 2018, the increase was 43%, indicating that yields are now rising at a slower rate than in previous decades[2]. The increase in crop yields was largely due to increased irrigation, improved crop varieties, agrochemical inputs, and improved soil and water management. However, the increase in crop productivity is not expected to continue indefinitely. In most parts of the world, yields for major crops have begun to stagnate[3][4]. Climate change, soil degradation, and salinization of irrigated areas will potentially limit future increases in production. Ray et al.[5] have shown that with the current rate of yield increase, it is not possible to meet the expected food demand by 2050. They have argued that some level of cropland expansion is needed to meet the food production deficits but at a higher environmental cost to biodiversity.

The amount of food available for human consumption is affected by the allocation of crops to other nonfood uses such as animal feed, bioenergy, and industrial uses. Globally, only 67% of the crop produced (by mass) or 55% of the calories produced is available for direct human consumption[6]. The remaining crop was allocated to animal feed (24% by mass) and other industrial use, including bioenergy (9% by weight). Animal production is less efficient than crop production in converting feed to human edible food[7][8][9][10]. As a result, only 12% of the 36% of the global calories used for animal feed will ultimately contribute to human diets[6].

In 2011, the global water footprint (WF) of agricultural production was 8362 km3/year (80% green, 11% blue, and 9% grey)[11]. World water demand is expected to increase by 20%–30% between 2010 and 2050[12]. Demand for land and water resources has increased significantly, and these resources are expected to be scarcer in the future. Efficient water management in agriculture is needed to meet the growing demand for food and reduce poverty and hunger in a sustainable manner. The question is how the world will feed the global population without further impacting the freshwater and ecosystems. Several researchers have advocated for sustainable intensification [10][13][14][15][16], dietary changes, and reduction of food waste and loss[17][18][19] to feed the world. A number of studies have shown the value of virtual water trade in global water saving, reducing water scarcity, and it will help to reduce the risk of water scarcity[20][21][22][23]. This paper provides a brief review of the WF of food production, the water demand for different food products and diets, and the WF of food loss and waste.

2. From Quantification to Sustainability Assessment

Over the last few years, the assessment of WFs of national consumption and production has shown significant improvement in terms of product coverage, spatial and temporal detail, and sustainability assessment[24]. Hoekstra and Hung[25] were the first to estimate the WF of national consumption of 38 crops for a large number of countries. The second global assessment made a number of improvements in terms of product coverage by including all crops and livestock products and other refinements[26][27]. The third global study made further refinements by assessing the national water footprints of production and consumption at a high spatial and temporal resolution[11][28]. In addition to the global studies on the WF of crop production mentioned earlier [29][30][31][32][33][34][35], other national[36][37][38][39][40], regional or basin[41][42], and global studies[28][43] have also traced and mapped the WF of consumption per country, but none of these studies assessed the sustainability of the blue WF of consumption at the place of production. The blue WF is unsustainable if it is above the available renewable blue water and violates the environmental flow requirements.

Van Oel et al.[44] carried out the first assessment of the sustainability of the WF in relation to Dutch consumption. In a case study for France, Ercin et al.[45] assessed the sustainability of the WF of consumption of France, identifying priority basins and products. Hoekstra and Mekonnen[46] assessed the sustainability and water-use efficiency of the UK’s WF of consumption. There are more recent works that have assessed the unsustainable blue WF of consumption for a single country or EU as a whole[47][48]. A few studies have assessed the sustainability of the WF of crop production and virtual water flows at a global level[49][50][51]. Other studies focused on sustainability of groundwater use[52][53][54][55][56].

In a more detailed global study, Mekonnen and Hoekstra[57] estimated that 513 km^3/year, or 57% of the blue WF, related to crop production, was unsustainable. Approximately 75% of the global unsustainable blue WF is related to the production of only six crops (Figure 1). These are wheat, rice, cotton, sugar cane, fodder, and maize. Five countries account for about 70% of the unsustainable blue WF (Figure 1), India, China, the US, Pakistan, and Iran.

Of the total unsustainable blue WF, 90% was for food and fodder crops, while only 10% was for fiber crops, rubber, and tobacco. Figure 2 shows the sustainable and unsustainable blue WF for global cereal production. The unsustainable portion of the blue WF is large in the Indus and Ganges river basins in India and Pakistan, in the north-eastern part of China, and in the US. High Plains aquifer. The study also showed that some 25% of global blue water can be saved by reducing the WF of each crop to the benchmark level.

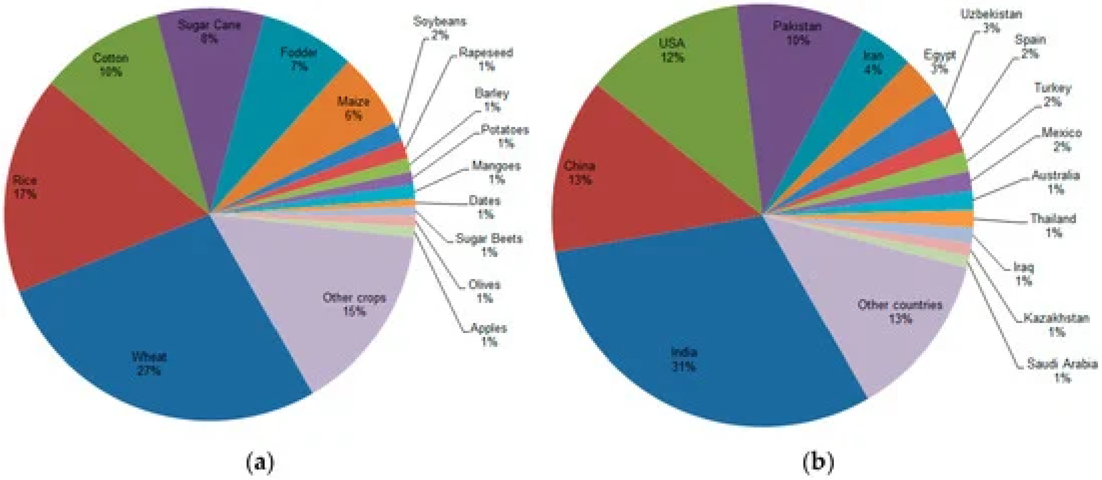

Figure 1. The unsustainable blue WF related to crop production: (**a**) Contribution of different crops toward the global blue unsustainable blue WF of crop production; (**b**) location of the unsustainable blue WF of crop production. Data source from Mekonnen and Hoekstra[57].

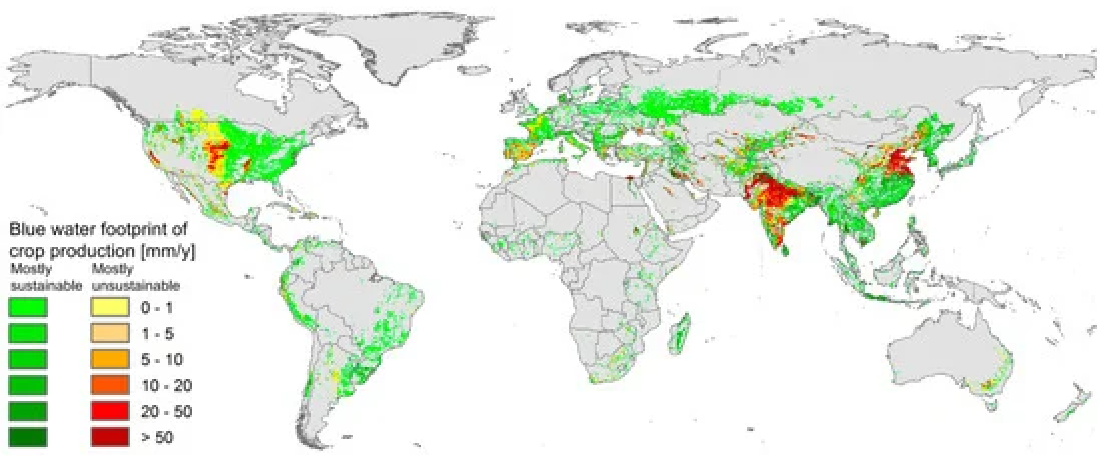

Figure 2. The sustainable (green) and unsustainable (yellow to dark red) parts of the blue WF of global cereals production. Data source from Mekonnen and Hoekstra[57].

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