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Water loss associated with food loss and waste in Brazil

Perda de água associada a perda e desperdício de alimentos no Brasil

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ABSTRACT

This article aimed to estimate the loss of water associated with food loss and waste in Brazil in 2013. Data from the Food and Agriculture Organization (FAO) of the United Nations (UN) on food balance and waste, as well as the Water Footprint (WF) of agricultural products available at Water Footprint Network (WFN) were used. Results show that food waste reaches 49 million metric tons per year, compromising a total of 87 billion cubic meters of water, which is higher than the average annual flow of the river São Francisco. Major water loss is associated with the agricultural production stage (32%), followed by consumption (19%). Amongst food groups, major water loss is associated with meat (49%), followed by cereals (19%). Roughly 96% of water loss is attributed to the green water component, which highlights that attention must be paid to rainfed agriculture to ensure food and water for everyone. The loss of blue water was more than half of the volume consumed in the urban sector, and the grey component (polluted water) was equivalent to 80% of this consumption. Measures such as improving agricultural practices, logistics, irrigation, expanding and improving rainfed agriculture, developing campaigns and policies to reduce exportation of primary products, as well as consumption of products from animal origin, can contribute to managing the food supply chain more sustainably when the focus is water. Reducing food loss and waste means preserving water.

Keywords: agriculture; water-energy-food nexus; water footprint; virtual water; green water.

RESUMO

Neste artigo estimou-se a perda de água associada aos alimentos desperdiçados no Brasil no ano de 2013. Tomou-se por base estudo da Organização das Nações Unidas para Agricultura e Alimentação (FAO) sobre desperdício de alimentos, o banco de dados FAOStat com o balanço de alimentos e o banco de dados de Pegada Hídrica (PH) de produtos agrícolas disponíveis na Water Footprint Network (WFN). Os resultados mostram que as perdas e desperdícios de alimentos atingem 49 milhões de toneladas por ano, comprometendo um volume anual de água de 87 bilhões de metros cúbicos, superior à vazão média anual do Rio São Francisco. A principal parcela das perdas de água está associada às perdas de alimento na etapa de produção agrícola (32%), seguida da de consumo (19%). Dentre os grupos de alimentos, as maiores perdas de água estão associadas às carnes (49%), seguida pelo grupo de cereais (19%). Cerca de 96% das perdas de água referem-se à água verde, o que evidencia a necessidade de uma maior atenção à agricultura de sequeiro para assegurar alimento e água para todos. A perda de água azul foi superior à metade do volume consumido no setor urbano; e a parcela cinza (água poluída) equivaleu a 80% desse consumo. Medidas como melhoria das práticas agrícolas, logística, irrigação, expansão da agricultura de sequeiro, desenvolvimento de campanhas e políticas para redução da exportação de produtos primários, bem como do consumo de produtos de origem animal, podem contribuir para uma gestão mais sustentável da cadeia de suprimento de alimentos quando o foco é a água. Reduzir a perda e o desperdício de alimentos significa preservar água.

Palavras-chave: agricultura; nexo água-energia-alimento; pegada hídrica; água virtual; água verde.

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Introduction

Data from the Food and Agriculture Organization (FAO) of the United Nations (UN) show that, every year, about a third of the food produced worldwide is not consumed by the population, being lost throughout the production chain, or wasted in the endpoint (restaurants and households) instead. This represents about 1.3 billion metric tons of food that is not used or, in monetary value, approximately US$ 1 trillion (FAO, 2014).

This situation tends to be even more aggravated with the growth of the world population. According to the United Nations Department of Economic and Social Affairs (2019), by the middle of this century, the world population will reach about 10 billion people. Concerning Brazil, the population is estimated to be around 238 million inhabitants by 2050, according to the intermediate projection (United Nations, 2019). In order to feed this additional population and include the current 870 million hungry people and two billion people who suffer from moderate to severe food insecurity in the country (FAO, 2019), it would be necessary to increase food supply by 70 to 100% (Alexandratos and Bruinsma, 2012; Reddy, 2016). In this scenario, the agricultural sector in Brazil would be pressured to increase production.

Nevertheless, agriculture is one of the greatest drivers for the transgression of planetary boundaries, including the use of freshwater (Campbell et al., 2017). Overall, this sector accounts for 70% of the total water withdrawal, with regional variations of 44% in the countries of the Organisation for Economic Cooperation and Development (OECD), 87% in Africa, and more than 90% in some Middle Eastern countries (Campbell et al., 2017). In Brazil, the consumptive water use for agricultural production in 2017 was 78.3% of the total consumed of 1,109 m^3/s, an increase of 21% compared to 2006, *versus* 6% for the industrial sector (ANA, 2019). In a broader view, considering the rainwater stored in the soil (green water), agricultural and livestock production accounts for 92% of all water used by humanity (Hogeboom, 2020).

This scenario already points to the threat of exceeding the limit of freshwater use. The Millennium Ecosystem Assessment Report (MEA) warned of this when it estimated, with low to medium certainty, that this limit was already exceeded by 5 to 25% (Millennium Ecosystem Assessment, 2005). More recently, Jaramillo and Destouni (2015) estimated the total freshwater use at $4.664 \cdot 10^{12}$ m^3 per year. The Stockholm Resilience Centre proposed a freshwater use limit of $4.0 \cdot 10^{12}$ m^3 per year (Rockström et al., 2009). This number, however, has been criticized for not considering regional specificities and/or the flow of green water (Bogardi et al., 2013; Gerten et al., 2013; Steffen et al., 2015). This limit had a revision suggested to be $2.8 \cdot 10^{12}$ m^3 per year, which is the mean value within an uncertainty range from $1.1 \cdot 10^{12}$ m^3 to $4.5 \cdot 10^{12}$ m^3 per year (Gerten et al., 2013). Assuming the consumption suggested by Jaramillo and Destouni (2015), the most conservative value of $2.8 \cdot 10^{12}$ m^3 per year and the most liberal of $4.0 \cdot 10^{12}$ m^3 per year would already be exceeded, by 67 or 17%, respectively. Such criticism led to the revision of the safe limit for the use of freshwater on Earth, considering the diverse flows, and climatic and ecosystem particularities of the various regions, aiming at a more robust definition of this limit (Gleeson et al., 2020), but the indications are of a water scarcity situation.

Meanwhile, tonnes of food are lost and/or wasted daily (FAO, 2013). Food Loss and Waste (FLW) occur both in developed and developing countries, although at different stages of the food chain for each case (Gustavsson et al., 2011). In the case of developing countries, such loss occur mainly due to the lack of infrastructure and investment in storage structures, whereas in developed countries, the origin is in the stages of distribution and consumption (Godfray et al., 2010).

The FLW occur throughout the supply chain, which involves the production, storage, transportation, processing, distribution, and consumption of food; and reflects significant equivalent water loss, revealing the inefficiency in the use of this critical resource and imposing an additional difficulty to fully meet future demands.

In Brazil, water security is considered a regional issue, given that the spatial distribution of the large water resources in the country is extremely unequal. The major availability, in which the worrying, critical or very critical level has not yet been reached, is found in areas of high ecological interest: the Cerrado region, the Amazon Forest, and the Pantanal (ANA, 2019).

The order of magnitude of FLW and, consequently, of water wasted, is large enough to deserve greater attention from the managers and users of this resource. Strategies that focus on reducing loss along the food production chain, and on the efficient and sustainable use of water, are crucial to achieving the Sustainable Development Goal No. 2 (Lundqvist et al., 2008). Doubling production simply implies that water damage will also double.

Thus, knowing the volumes of water wasted due to FLW will enable the managers of this resource to define priorities to tackle the problem. The appropriate indicator for this is the Water Footprint (WF), used to evaluate the volume of water needed for each agricultural product and its portions of blue water, the most cited and the one which corresponds to what is extracted from rivers, lakes, and aquifers; green water, stored in the soil and used by plants; and grey water, the volume of water polluted as a result of the activity (Hogeboom, 2020).

The Water Footprint Network (WFN) defines the WF of a product as the total volume of freshwater used directly or indirectly to produce that product and can be decomposed into the blue, green, and grey components (Hoekstra et al., 2011). The WF can be considered as a comprehensive indicator of the appropriation of water resources, *vis-à-vis* the traditional and restricted concept of water withdrawal. The WF of a product is the volume of water used to produce it, measured throughout the entire production chain (Hoekstra et al., 2011). It is, therefore, an indicator of the appropriation of the freshwater resource as opposed to the traditional and restricted measurement of water withdrawal.

The concept of WF has been widely used in agricultural and livestock production, with a large number of studies evaluating the impact of agricultural products on the water system (Ding et al., 2018; Xinchun et al., 2018; Fulton et al., 2019), livestock (Barden et al., 2017; Asevedo et al., 2018), forestry (Schyns et al., 2017), agroindustry (Bleninger and Kotsuka, 2015; Munoz Castillo et al., 2017), besides being used to support water management (Empinotti and Jacobi, 2013; Silva et al., 2016; Nouri et al., 2019).

However, relatively few studies assess the water loss associated with FLW. Except for the study of the water footprint of the FLW in the European Union (Vanham et al., 2015) and more recently research by Sun et al. (2018), the literature is limited to the blue water component, which is present in rivers and aquifers (Kummu et al., 2012; FAO, 2013; Le Roux et al., 2018; Spang and Stevens, 2018; Read et al., 2020) or does not identify the various components of water (Liu et al., 2013). A recent report evaluated the WF of bovine meat in Brazil, although without considering the loss (Pavão et al., 2020).

Nevertheless, given the importance of water in agricultural production, especially food, many authors have recommended the inclusion of the green water component in integrated water management (Rockström et al., 2014; Rodrigues et al., 2014; Schyns et al., 2015; Porkka et al., 2016; Falkenmark, 2018). This is particularly relevant for Brazil, whose culture is of an abundance of water, at a time when there is a growing trend of export of primary products.

Therefore, the objective of the present article is to assess the volume of water compromised due to food loss and waste in Brazil for the year 2013, which may constitute a subsidy for planning water allocation in the Brazilian agricultural production.

Material and Methods

The scope of this study is the food portion intended to meet domestic demand in Brazil for the year 2013. The most recent data are available on the FAO's statistics division website and Food Balance Sheet, FBS (FAOSTAT, 2015).

First, the loss throughout the Food Supply Chain (FSC) was estimated in terms of mass, then the volume of water needed to produce these foods was calculated (Figure 1).

Differently from the related and global scope literature, which has accounted only for the volume of water withdrawn for irrigation (blue water), this study also accounts for the components associated with the rainfed production (green water) and water for diluting the residues generated (grey water).

Food loss and waste accounting

Data concerning food production and use were obtained from the FAOSTAT's and FBS's websites (FAOSTAT, 2015) for the year 2013, Brazil. The food groups were organized as shown in Table 1.

The elements contained in the FBS have been divided into production and utilization elements. For each product group, the Quantity intended for Domestic Supply (QDS) is equal to the sum of production, import quantity, stock variation, and export quantity. The food available for human consumption is QDS minus other utilization elements, such as feed, seeds, processing, and others (Figure 2).

The calculations to estimate loss and waste were carried out for each food group separately, to take into account their specificities. The method was based on the FAO report, entitled Global Food Losses and Food Waste (Gustavsson et al., 2011), which was later detailed in the publication entitled The Methodology of the FAO Study: " Global Food Losses and Food Waste-extent, causes and prevention" - FAO, 2011 (Gustavsson et al., 2013).

Allocation factors (af) were used to estimate the fraction of the production intended for human consumption. Conversion factors (cf) were applied to determine the edible portion of primary products. The values provided by Gustavsson et al. (2013) for Latin America were adopted, as shown in Table 2. Based on the same method, the evaluation was made considering five stages of the supply chain whose percentages of loss are shown in Table 3.

Water footprint

This study included the component associated with the agricultural production stage alone, which is the most important, although water could be considered to be also used in the stages of processing and consumption. In this sense, factors such as climate, soil and crop management, crop varieties, among others, directly affect their accounting.

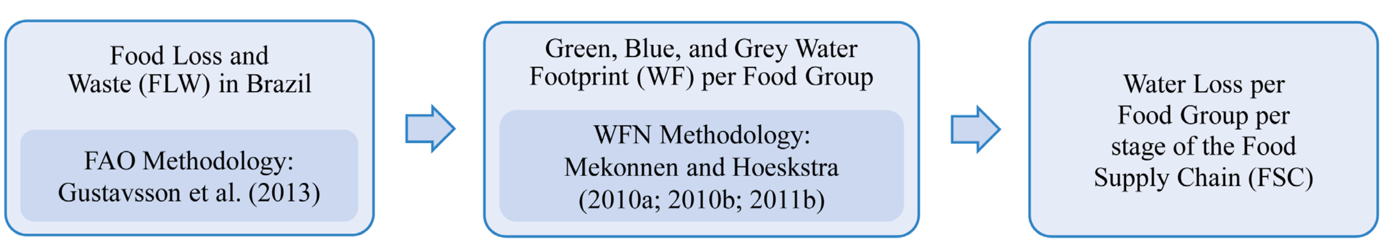

Figure 1 – Stages of the study.

To estimate the green, blue, and grey WF of agricultural and animal products, the studies by Mekonnen and Hoekstra (2010a; 2010b; 2011b) were used, whose annexes present the values of these indicators referring to the food produced in several countries, including Brazil. This study considered the value of the global average for the country.

The WF calculation for each group of food was performed according to Equation 1.

$$\sum WF_{\text{Group n}} = \frac{P_1 \cdot WF_1 + P_2 \cdot WF_2 + P_n \cdot WF_n}{P_1 + P_2 + P_n} \quad (1)$$

In which:

WF = water footprint ($m^3 \cdot t^{-1}$);

P = production of each food (t).

Results and Discussion

Based on the methods used, it is estimated that Brazil lost, in the FSC, about 49 million metric tonnes of food in 2013, which represents 39% of the QDS that includes the portion intended for human consumption (Table 4).

These losses and wastes occur throughout the FSC, from cultivation to final consumers, with emphasis on the initial stages in emerging countries such as Brazil. About 38% of the FLW occur in the production stage, followed by 22% in post-harvest and storage, 15% in processing and packaging, 13% in distribution, and 12% in the consumption stage.

Even though the consumption stage has the lowest contribution to the total FLW, it is still surprising that about 6 million tonnes are wasted in Brazilian households. This value may be underestimated in view of a study by Porpino et al. (2015) that points to high waste generation during the consumption stage in the lower-middle-class population, which can be associated with cultural traits, which differentiates Brazil from countries with equivalent *per capita* income in which the loss in this stage is small.

This situation is aggravated considering that about 39.4% of households in the country live in food insecurity (Araújo et al., 2020). Furthermore, 5% of all disease burdens in Brazil are associated with food shortages (GBD 2016 Brazil Collaborators, 2018).

In terms of mass, the food group with the highest percentage of loss was fruit and vegetables. According to the Paraná Institute of Technical Assistance and Rural Extension (*Instituto Paranaense de Assistência Técnica e Extensão Rural*), EMATER (Trento et al., 2011) the agribusiness of fruits and vegetables faces several problems such as low productivity, low quality, and high production costs; environmental and sanitary problems in production, processing, and marketing; deficiency in storage, transport, and marketing logistics; low consumption and restricted eating habits; lack of more advanced technology and market knowledge. Due to the fragility of these products, the greatest loss occur in the agricultural production system and in transportation, in which the distance between production and consumption sites is a determining factor.

The cereals group was a major agricultural production with 97 million tonnes, of which 79 million were allocated to the domestic market. Compared to another group of high gross production, oilseeds and legumes, whose total production was 90 million tonnes, only 47 mil-

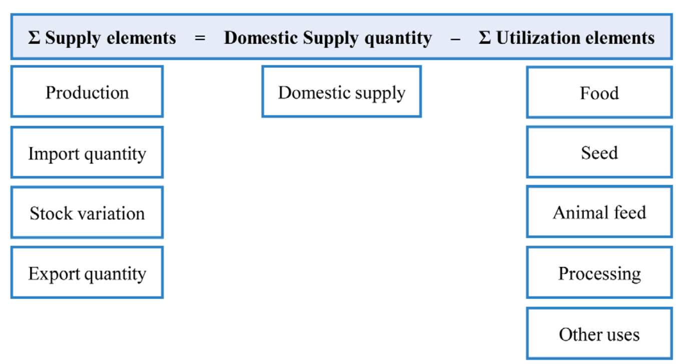

Figure 2 – Food mass balance.
Source: Gustavsson et al. (2011).

Table 1 – Food groups.

Group	Food
Cereals	Wheat, rice, barley, maize, rye, oats, millet, sorghum, and other cereals
Roots and tubers	Cassava, yam, potatoes, and sweet potatoes
Oilseeds and legumes	Soybeans, peanuts, sunflower, grape pomace and mustard seed, cotton seed, coconuts, sesame seed, palm seed, olives, and other oilseeds
Fruits and vegetables	Orange and mandarin, lemon and lime, grapefruit, other citrus fruits, banana, apple, pineapple, date, grape, other fruits, tomato, onion, and other vegetables
Meat	Bovine meat, mutton/goat meat, pork meat, and bird meat
Milk and eggs	Milk (not including derivatives) and eggs

Table 2 – Allocation factors and conversion factors for food groups.

Food group	Stage of the chain				
	Agricultural production	Post-harvest and storage	Processing and packaging	Distribution	Consumption
Cereals	0.40 (af)	0.40 (af)	-	-	-
Roots and tubers	0.82 (cf)	0.82 (cf)	0.90 (cf)	0.74 (cf_m) 0.90 (cf_i)	0.74 (cf_m) 0.90 (cf_i)
Oilseeds and legumes	0.12 (af)	0.12 (af)	-	-	-
Fruits and vegetables	0.77 (cf)	0.77 (cf)	0.75 (cf)	0.80 (cf_m) 0.75 (cf_i)	0.80 (cf_m) 0.75 (cf_i)
Meat	-	-	-	-	-
Milk	-	-	-	-	-

af: allocation factor; cf: conversion factor; i: industrial; m: manual.
Source: Gustavsson et al. (2013).

Table 3 – Values of the percentage of food loss per group for Latin America.

Food group	Stage of the chain				
	Agricultural production	Post-harvest and storage	Processing and packaging	Distribution	Consumption
Cereals	6%	4%	2.0% (g) 7% (p)	4%	10%
Roots and tubers	14%	14%	12%	3%(f)	4% (f) 2% (p)
Oilseeds and legumes	6%	3%	8%	2%	2%
Fruits and vegetables	20%	10%	20%	12% (f) 2% (p)	10% (f) 1% (p)
Meat	5.6%	1.1%	5%	5%	6%
Milk	3.5%	6%	2%	8%	4%

m: grinded; f: fresh; p: processed.
Source: Gustavsson et al. (2013).

Table 4 – Food Loss in Brazil in 2013.

Stage	Food loss (10^3·t)						
	Cereals	Roots and tubers	Oilseeds and legumes	Fruits and vegetables	Meat	Milk	Total
Agricultural production	2,480.6	3,406.6	857.3	9,174.9	1,543.0	1,330.2	18,792.7
Post-harvest and storage	1,554.5	2,929.7	402.9	3,670.0	286.1	1,959.2	10,802.4
Processing and packaging	1,869.0	965.3	711.2	2,235.0	977.6	607.2	7,365.3
Distribution	745.7	264.9	284.3	1,581.8	928.7	2,416.5	6,222.0
Consumption	2,147.6	201.8	278.6	1,064.2	1,058.7	1,147.4	5,898.4
Total	**8,797.4**	**7,768.4**	**2,534.4**	**17,725.9**	**4,794.2**	**7,460.6**	**49,080.7**

lion were allocated to the domestic market.The difference between these proportions has implications for losses in the processing, distribution, and consumption stages.

The relative loss in the FSC reached 70% in the roots and tubers group, and 61% in the fruit and vegetable group. The more animal products, and fruits and vegetables in the diet, the less is the durability of food, thus increasing the loss. This is driven by the growth of urbanization rates that increases the distance between the production and consumption sites, demanding more transportation.

These losses also imply substantial financial losses. The Brazilian Institute of Applied Economic Research (*Instituto de Pesquisa Econômica Aplicada* - IPEA) (Carvalho, 2009) cites a study by the Department of Supply and Agriculture of São Paulo State, which estimated the value of food loss at 1.4% of Brazil's Gross Domestic Product, worth R$ 17.25 billion at the time.

In addition to other economic, social, and environmental impacts, FLW should be associated with the loss of water used in food production, which is usually ignored in scientific work focused on this subject and virtually absent in the official documents that deal with water management. The WF and its components for each food group are shown in Table 5.

Table 6 shows the WF associated with FLW by stage of the chain per food group. The greatest impact occurs on agricultural production. The total value of water loss reached 87.3 billion m^3 in 2013. This is equivalent to 2,768 m^3/s, which is in the same order of magnitude of the average long-term flow at the source of the river São Francisco Basin, equal to 2,914 m^3/s or three times the offerable flow of 875 m^3/s (ANA, 2019). It is almost an entire river São Francisco wasted.

According to Falkenmark and Rockström (2008), the water used in the production of the amount of food to meet a person's needs is 1,300 L/day, considering 20% of calories being of animal origin. The virtual water from FLW would therefore be sufficient to produce food for a population of about 180 million people, which corresponds to roughly 90% of the Brazilian population in the study year (IBGE, 2013).

The value of this loss in 2013 was 435.0 m^3 per capita, corresponding to about 20% of the average WF of consumption of each Brazilian, which is equivalent to 2,027 m^3/year (Mekonnen; Hoekstra, 2011a).

The major share of water loss is associated with loss in the agricultural production stage (32.1%), followed by consumption (18.7%), processing and packaging (18.5%), distribution (16.8%), and, finally, post-harvest and storage (13.9%).

Moreover, according to the results in Table 6, the analysis of the total WF per food group shows a greater contribution of meat, which is associated with 49.2% of water losses, followed by the group of cereals (19.0%), milk and eggs (12.1%), fruits and vegetables (9.5%), oilseeds and legumes (6.3%), and roots and tubers (3.8%). The FLW of animal products account for more than half of the total water loss.

Considering the three components of WF (green, blue, and grey), the largest contribution to the total WF comes from the green component, 96.0% (Figure 3), which has no direct impact on watercourses. However, several authors (Rockström et al., 2014; Rodrigues et al., 2014; Schyns et al., 2015; Porkka et al., 2016; Falkenmark, 2018) warn both of the mistake of seeing only blue water as a productive resource and of the strong dependence of food production by green water. The green component can account for up to 97% of the water used in this activity and support this concern realizing that the appropriation of this resource towards society compromises the maintenance of ecosystem services.

Blue water and green water work as "communicating vessels", and their availability depends on precipitation, which is, ultimately, the allocated resource. The main distinction between one and the other is that green water is allocated according to decisions on land use, whereas blue water can be captured at distant points from where precipitation fell (Schyns et al., 2019). Due to this "invisibility" of green water, the limits of its use and the use of associated scarcity indicators have only recently been debated and researched, such as the study in the agricultural basin of the Cantareira system (Rodrigues et al., 2014), and the review and classification article of indicators of availability and scarcity of green water (Schyns et al., 2015). Schyns et al. (2019) propose a green water Scarcity Index, given by the relation between the total green WF of the area and the maximum sustainable green WF, the latter being equal to total green WF minus that of the reserve of 17% to ensure the biodiversity target and areas without aptitude for agriculture. This method was applied on a planetary scale with a cell mesh of

Table 5 – Water footprint by component per food group.

WF component	Water footprint (m^3/t)						
	Cereals	Roots and tubers	Oilseeds and legumes	Fruits and vegetables	Meat	Milk	Total
Green	1,712.8	407.8	2,153.4	431.8	8,669.1	1,350.8	14,725.6
Blue	46.2	3.8	2.9	15.7	141.9	38.4	249.0
Grey	131.1	17.0	20.9	20.0	152.7	25.3	367.0
Total	1,890.1	428.6	2,177.2	467.5	8,963.8	1,414.5	15,341.6

Source: Mekonnen and Hoekstra (2010a; 2010b; 2011b).

5 × 5-minute arc; and the results show that 56% of the availability of green water in the world is already used, 51% in Brazil (Schyns et al., 2019). These are aggregated values that do not include cases of use of the green WF flow in protected areas, whose overall value is 18% and, for Brazil, 14% (Schyns et al., 2019).

On the other hand, green WF is the main resource for agricultural production, since the urban and industrial supply depends exclusively on the blue water flow. Thus, aiming at meeting an increasing demand for food, the reduction of FLW should be associated with what is called sustainable intensification of rainfed agriculture by adopting techniques that increase and retain moisture in the soil for longer, in addition to the application of water according to the concept of supplementary or deficit irrigation (Reddy, 2016; Schyns et al., 2019).

The blue and grey WF, which are the components that have an impact on water bodies, represent approximately 136 m^3/s, or about 50% of the entire availability of the East Atlantic Hydrographic Region, where 15 million people live (ANA, 2019). This number is also equivalent to 70% of all water consumed by the Brazilian industrial sector. Another way to look at this number is to compare it with the sum of all the flows for urban supply in Brazil in 2018, whose value was 501 m^3/s (ANA, 2019).

Even though the absolute numbers of food waste are already alarming *per se*, there are a set of built-in wastes that further cloud the global scenario. The production and distribution stages in the FSC need land, mineral fertilizers, pesticides, electricity, fossil fuels, and, above all, water. Wasted food buries all these resources with it (Rodrigues, 2017).

Table 6 – Water footprint of food loss by stage of the chain per food group.

Stage of the chain	Water footprint by food group (10^9 m^3/year)						
	Cereals	Roots / tubers	Oilseeds / legumes	Fruits / vegetables	Meat	Milk	Total
Agricultural production	4.69	1.46	1.87	4.29	13.83	1.68	28.0
Post-harvest and storage	2.94	1.26	0.88	1.72	2.56	2.77	12.1
Processing and packaging	3.53	0.41	1.55	1.04	8.76	0.85	16.2
Distribution	1.41	0.11	0.62	0.74	8.32	3.32	14.6
Consumption	4.06	0.09	0.61	0.50	9.49	1.53	16.4
Total	**16.63**	**3.33**	**5.52**	**8.29**	**42.97**	**10.13**	**87.3**

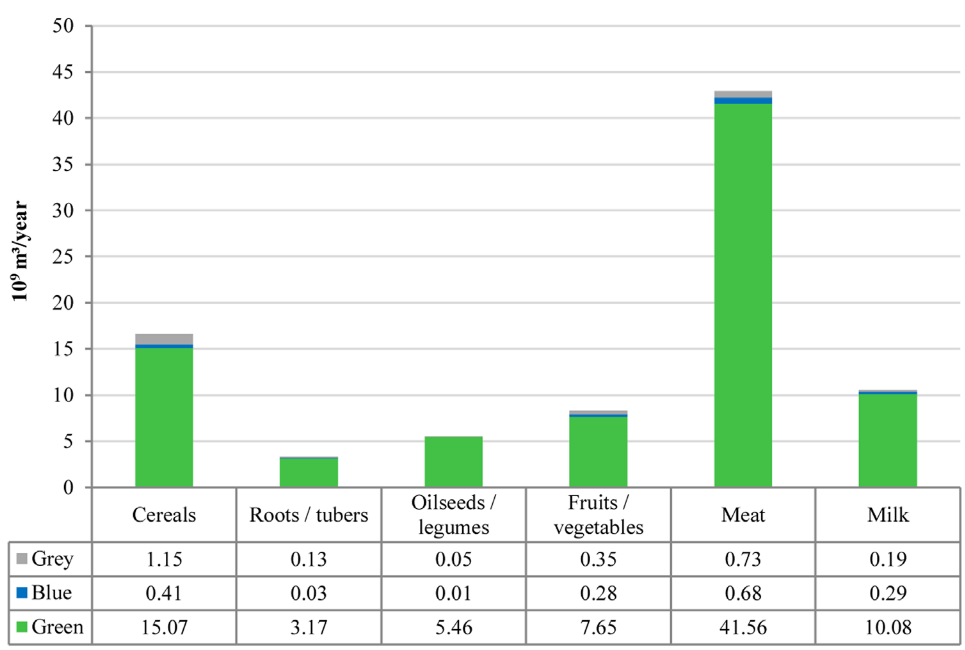

Figure 3 – Water footprint by component per food group.

Reducing FLW throughout the FSC may be the best strategy towards sustainability within food security. At the same time, this reduction can represent a relief in the pressure on water bodies, saving water for other uses, including environmental demands.

Food production is the activity with the largest water use in Brazil, accounting for 79.2% of the total consumption in 2017, or a flow of 917.1 m^3/s (ANA, 2019), which is in the same order of magnitude as the world's average. Meeting the 12.3 goal of the Sustainable Development Goals of halving the FLW by 2030 would mean, alone, the availability of 458.6 m^3/s, equivalent to about 90% of the total withdrawal for urban supply.

The current situation of water use already demands attention. Vörösmarty et al. (2010) analyzed the world's water resources and found that the incidence of a threat to water security was high in many regions, including Brazil. Roughly 11,500 km of rivers have withdrawals above 20% of their availability, of which 4,900 km have withdrawals over 70% (ANA, 2019). Not coincidentally, the concentration of watersheds in critical situations occurs where the largest populations are also concentrated. Despite the claimed abundance of water, extensive areas are under threat.

The food production system, therefore, urges for critical advances in water use efficiency. On the one hand, both reducing losses before considering increasing production capacity (Freire Junior and Soares, 2014) and minimizing their implications for water resources must be key concerns; and, on the other hand, an increase in the productivity of water use in agriculture is needed.

The first approach consists of goal 12.3 of the Sustainable Development Goals (SDGs): by 2030, halve the global food waste *per capita* at retail and consumer levels, and reduce food loss along the production and supply chain, including post-harvest loss.

In less developed countries, which includes Brazil, FLW can be associated with factors that mainly penalize the initial stages of the FSC. The main factors pointed out are improper management, inadequate harvesting techniques, inappropriate post-harvest management, lack of logistics infrastructure, irregular processing and packaging, and poor-quality marketing information (Gustavsson et al., 2011; Lipinski et al., 2013; Dung et al., 2014).

Nevertheless, attention must also be focused on the consumption stage, which represents 12% of the FLW. Various reasons for loss in this stage can be pointed out: lack of awareness of the amount of food wasted by consumers or the impact it causes; income high enough to afford wasting; high-quality standard and sensitivity to food security; lack of planning for the acquisition of food, which results in overbuying; lack of ability in the kitchen to size the portions in each meal; and changes in daily planning due to busy routine (Kibler et al., 2018).

The World Resources Institute (WRI), linked to the United Nations Environment Programme (UNEP), suggests several measures, listed in Table 7, without, however, claiming to exhaust the possibilities (Lipinski et al., 2013).

It is worth adding, among other measures, food production in the concept of urban and peri-urban agriculture of perishable products, such as some horticulture producers (Kibler et al., 2018). This could have a strong impact on the loss observed in these food groups, which is mainly influenced by transportation.

Concerning the increasing water efficiency in food production, the relevance of green water cannot be ignored: rainwater stored in soil and which sustains rainfed agriculture. Conservation practices such as terracing, land leveling, soil fertility management, tillage, sediment, and moisture containment dams, etc.

Table 7 – Potential approaches to reduce food loss and waste per stage.

Production	Post-harvest and storage	Processing and packaging	Distribution and marketing	Consumption
Facilitate the donation of inadequate crops to the market	Improve access to low-cost storage technologies	Reengineer manufacturing processes	Facilitate the donation of unsold products	Facilitate the donation of unsold products in restaurants
Improve the availability of extension services	Improve the management of the ethylene and microorganisms in the storage stage	Improve supply chain management	Change practices on food date labels	Run consumer education campaigns
Improve market access	Use low-carbon cooling techniques	Improve packaging to keep products fresh longer	Modify promotions in the market	Reduce the size of the served portions
Improve harvesting techniques	Improve transport infrastructure		Provide consumer guidance on food storage and preparation	Ensure home economics education in schools, universities, and communities

Source: Lipinski et al. (2013).

can increase and retain soil moisture for longer, reducing water loss by evaporation given the same amount of rain (Springer and Duchin, 2014). Based on Falkenmark and Rockström (2006), the use of such techniques could potentially increase productivity by up to 50% in Latin America.

This claim is shared by de Fraiture and Wichelns (2010) when they state that, for a scenario with high productivity of rainfed agriculture, the demand for food in 2050 could be met by increasing 7% of the cultivated rainfed area, without the expansion of the irrigated area.

In the opposite direction, the Brazilian Government, through the Ministry of Agriculture, Livestock, and Supply (MAPA), has been adopting measures aimed at expanding the irrigated area. Between 1960 and 2015, the irrigated area grew from 455,000 to 6.95 million hectares, equivalent to an average growth rate of 6% per year. Furthermore, adding 2.8 million hectares by 2020 was also planned, and another 7.0 million from 2020 to 2030 (Rocha and Christofidis, 2015).

From the point of view of water management, there are two trends that should foster demand over the next few years. One is the consolidation of the economic model based on the export of primary products, as shown in Figure 4. Brazilian exports in the last fifty years of bovine meat, chicken meat, soybean, and maize have grown 27, 1,000, 450, and 2,000 times, respectively (FAOSTAT, 2015).

Godfray et al. (2010) draw attention to the need of better understanding the effects of globalization on the food production system and its externalities. According to Mekonnen and Hoekstra (2011b), Brazil's exports in primary products are equivalent to 110 billion cubic meters of virtual water, *versus* an import of 33 billion. This situation characterizes the country not only as an exporter of water, but also of land and soil fertility.

In a pandemic situation, as occurred in 2020 with COVID-19, a new geopolitical context is observed. Given the scarcity of water, it is natural for developed economies to seek to avoid wasting it for production. As such, they opt for importing from countries capable of providing them with this resource at competitive prices. However, international trade in agricultural products may be affected by the rise of neo-nationalism after the COVID-19 pandemic (Brasil, 2020). Virtual water export management, for instance, can be considered as a measure to defend food sovereignty and self-sufficiency, which some authors refer to as post-pandemic neo-nationalism.

For example, for a highly water-intensive activity such as livestock, there was an increase in the Brazilian cattle herd by 23% between 2000 and 2010, when there was a widespread decrease in the number of cattle herds in the European Union and the United States (FAOSTAT, 2015).

Brazil is an important soybean exporting country. Additionally, according to the Department of Rural Socio-Economic Studies (2007), a significant replacement of animal greases by vegetable oils has been observed worldwide, due to factors associated with health, production costs, industrial development, and versatility of this type of raw material. Furthermore, the increase in the Brazilian soybean production will continue for several reasons, including the increase of world population (especially in China); also the soybean potential as a raw material in biodiesel, paint, lubricant, and plastic industries; and a growth in the consumption of soybean meal to meet the rising meat industry worldwide and in Brazil (Dall'Agnol and Hirakuri, 2008).

Maize represented 76% of the production of cereals, the second largest group in WF associated with FLW, being an important commodity among Brazilian exports (Figure 4). This food group holds the largest blue WF and grey WF when compared to the others, both in absolute and relative terms. This highlights the importance of maize production as a potential competitor for water allocation in the future.

The other trend is the growth of domestic demand for fruits and animal products, while the consumption of roots and tubers decreases, associated with the increase in *per capita* income. The world's *per capita* income is also expected to grow 4.5 times by 2050 compared to 2008 (Lundqvist et al., 2008). According to Benett's Law, cited by Parfitt et al. (2010), income growth leads to a transition in diet, i.e., an increase in the consumption of meat, fruits and vegetables, milk and dairy products, as well as a reduction in consumption of roots and tubers. In Brazil, meat consumption multiplied by 3.7 over the last 50 years; milk and dairy products, by 2.0; fruits and vegetables, by 1.5; cereals, by 1.2; and roots and tubers, by 0.7 (Figure 5).

With the growth of meat consumption in Brazil and the expectation of meeting the growing demand for agricultural products abroad, the impacts on water resources tend to worsen.

In addition to human activities, water waste can lead to a decrease in the number of species or number of individuals of the same species, affecting the balance of ecosystems (Figueiredo et al., 2017).

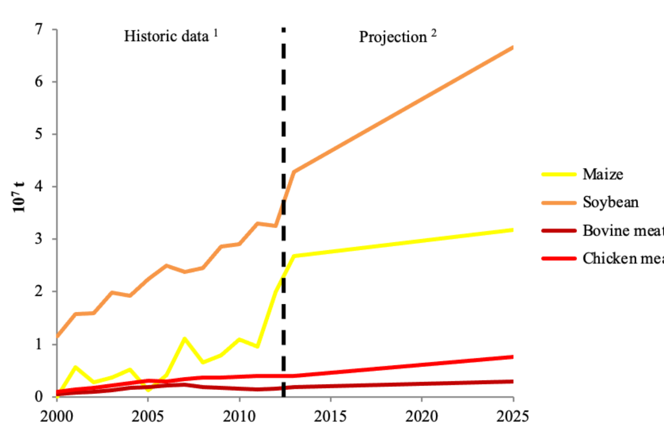

Figure 4 – Evolution of commodity exports by Brazil.
Source: FAOSTAT (2015).

Thus, greater attention must be paid to the efficiency in water use throughout the entire food production chain, from the agricultural production to the consumption stage, considering several factors that imply in this care, highlighting climate change notably.

Therefore, increasing the efficiency of the food production chain is imperative for all its extension, from the most efficient management of the rainfed agriculture, with better use of rain and the reduction of loss and waste, and even the incentive to the adoption of a diet based on fewer consumption of animal products.

Conclusion

Food loss and waste in Brazil were estimated at 49 million tonnes in 2013, according to FAO methodology (Gustavsson et al., 2013), with serious implications for water management in the country.

They result in a water loss of 87 billion cubic meters per year, or about 2,768 m^3/s, equivalent to 96% of the average flow of the river São Francisco in the source. This volume would be enough to produce food for 180 million people.

The largest water losses are associated with meat and cereals, corresponding to 49 and 19% of the total, respectively. This scenario can be aggravated by the increase in exports, whose agenda prioritizes maize, soybeans, and meats. Another aggravating factor is the change in eating habits of the Brazilian population, with increasing consumption of animal products, accounting for 61% of the entire volume of water lost.

Green water is the main resource for agricultural production, with a share of 96%. This flow is associated with land use and has a direct influence on the maintenance of ecosystem services, although it is ignored in water management. Greater attention should be given to this resource with the adoption of techniques that increase and retain soil moisture for longer, increase the efficiency of rainfed agriculture, and reduce the demand to expand irrigated areas.

The blue water footprint totals 53.6 m^3/s, which is equivalent to 52% of the consumptive use of the urban sector in 2013, which evidences the conflict between urban and agricultural uses. It should be highlighted that, for urban supply, blue water is the only option.

Grey water footprint accounts for 82.9 m^3/s and, although it does not necessarily require a quantitative reduction, it draws attention to the high volume of degraded water, as well as its environmental and economic implications, including from the eutrophication of water bodies to a greater energy demand for human and/or industrial use.

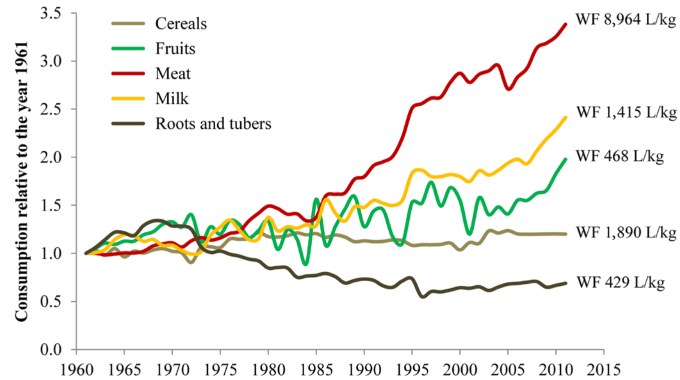

Figure 5 – Evolution of per capita consumption of some food groups in Brazil.
Source: FAOSTAT (2015).

Meeting goal 12.3 of the Sustainable Development Goals (SDGs), halving food loss and waste by 2030, would mean, alone, the availability of 458.6 m^3/s of freshwater. Key measures to achieve this goal are: improving agricultural practices, running campaigns aimed at consumers, improving transport infrastructure, and producing perishable products closer to the places of consumption.

Investment in improving water management in irrigated properties and sustainable intensification of rainfed agriculture would contribute to an additional gain.

Finally, the adoption of policies that redirect the model of primary products exports and campaigns to reduce the consumption of animal products would be an important advance in the preservation of water in Brazil.

A continuation of this work should address the water loss associated with food loss and waste considering specific regions throughout the years, including seasonal variations in agricultural activities such as drought (greater blue water demand) or excess rain (green water). A given water consumption has different effects in one region with adequate water availability and, in another, with a lack of this resource.

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References

Agência Nacional de Águas (ANA). 2019. Conjuntura dos Recursos Hídricos no Brasil: regiões hidrográficas brasileiras (Accessed on August 13, 2020) at: http://www.snirh.gov.br/portal/snirh/centrais-de-conteudos/conjuntura-dos-recursos-hidricos/conjuntura_informe_anual_2019-versao_web-0212-1.pdf

Alexandratos, N.; Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. FAO (Accessed August 13, 2020) at: http://www.fao.org/3/a-ap106e.pdf

Araújo, M.; Nascimento, D.R.; Lopes, M.S.; Passos, C.M.; Lopes, A.C.S., 2020. Condições de vida de famílias brasileiras: estimativa da insegurança alimentar. Revista Brasileira de Estudos de População, v. 37, 1-17. https://doi.org/10.20947/S0102-3098a110

Asevedo, M.D.G.; Sousa, W.L.; Dias, J.M., 2018. Pegada Hídrica da Produção de Suínos na Região Nordeste Brasileira. Revista Gestão & Sustentabilidade Ambiental, v. 7, (3), 504-517. http://dx.doi.org/10.19177/rgsa.v7e32018504-517

Barden, J.E.; Sindelar, F.C.W.; Buttenbender, B.N.; Silva, G.R., 2017. Pegada hídrica da produção de leite in natura: uma análise das principais regiões produtoras do Rio Grande do Sul. Revista de Administração da Universidade Federal de Santa Maria, v. 10, 117-128. https://doi.org/10.5902/1983465925413

Bleninger, T.; Kotsuka, L.K., 2015. Conceitos de Água Virtual e Pegada Hídrica: Estudo de caso da Soja e Óleo de Soja no Brasil. Recursos Hídricos, v. 36, (1). https://doi.org/10.5894/rh36n1-2

Bogardi, J.J.; Fekete, B.M.; Vörösmarty, C.J., 2013. Planetary boundaries revisited: a view through the 'water lens'. Current Opinion in Environmental Sustainability, v. 5, (6), 581-589. https://doi.org/10.1016/j.cosust.2013.10.006

Brasil. 2020. Ministério da Agricultura, Pecuária e Abastecimento. A Pandemia da COVID-19 e as Perspectivas para o Setor Agrícola Brasileiro no Comércio Internacional. Ministério da Agricultura, Pecuária e Abastecimento (Accessed on August 13, 2020) at: https://www.gov.br/agricultura/pt-br/campanhas/mapacontracoronavirus/documentos/a-pandemia-da-covid-19-e-as-perspectivas-para-o-setor-agricola-brasileiro-no-comercio-internacional/view

Campbell, B.M.; Beare, D.J.; Bennett, E.M.; Hall-Spencer, J.M.; Ingram, J.S.; Jaramillo, F.; Ortiz, R.; Ramankutty, N.; Sayer, J.A.; Shindell, D., 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecology and Society, v. 22, (4), 8. https://doi.org/10.5751/ES-09595-220408

Carvalho, D., 2009. Fome e desperdício de alimento. IPEA, Brasília (Accessed January 25, 2021) at: https://www.ipea.gov.br/desafios/index.php?option=com_content&view=article&id=1256:catid=28&Itemid=23

Dall'Agnol, A.; Hirakuri, M.H., 2008. Realidade e perspectivas do Brasil na produção de alimentos e agroenergia, com ênfase na soja. EMBRAPA (Accessed August 13, 2020) at: https://www.grupocultivar.com.br/ativemanager/uploads/arquivos/artigos/agronegocio_soja.pdf

Departamento de Estudos Socioeconômicos Rurais (DESER). 2007. Boletim Eletrônico do DESER (Accessed July 20, 2020) at: https://silo.tips/download/boletim-eletronico-do-deser-n-junho-200

Ding, D.; Zhao, Y.; Guo, H.; Li, X.; Schoenau, J.; Si, B., 2018. Water Footprint for Pulse, Cereal, and Oilseed Crops in Saskatchewan, Canada. Water, v. 10, (11), 1609. https://doi.org/10.3390/w10111609

Dung, T.N.B.; Sen, B.; Chen, C.C.; Kumar, G.; Lin, C.Y., 2014. Food waste to bioenergy via anaerobic processes. Energy Procedia, v. 61, 307-312. https://doi.org/10.1016/j.egypro.2014.11.1113

Empinotti, V.L.; Jacobi, P.R., 2013. Novas práticas de governança da água? O uso da pegada hídrica e a transformação das relações entre o setor privado, organizações ambientais e agências internacionais de desenvolvimento. Desenvolvimento e Meio Ambiente, v. 27, 23-36. http://dx.doi.org/10.5380/dma.v27i0.27928

Falkenmark, M., 2018. Shift in Water Thinking Crucial for Sub-Saharan Africa's Future. In: Biswas, A.K.; Tortajada, C.; Rohner, P. (Eds.), Assessing Global Water Megatrends. Springer, Singapore, pp. 147-177.

Falkenmark, M.; Rockström, J., 2006. The new blue and green water paradigm: Breaking new ground for water resources planning and management. Journal of water resources planning and management, v. 132, (3), 129-132. https://doi.org/10.1061/(ASCE)0733-9496(2006)132:3(129)

Falkenmark, M.; Rockström, J., 2008. Building resilience to drought in desertification-prone savannas in Sub-Saharan Africa: The water perspective. Natural Resources Forum, v. 32, (2), 93-102. https://doi.org/10.1111/j.1477-8947.2008.00177.x

Figueiredo, M.C.B.; Gondim, R.S.; Aragão, F.A.S., 2017. Produção de Melão e Mudanças Climáticas. EMBRAPA, Brasília.

Food and Agriculture Organization of the United Nations (FAO). 2013. Food wastage footprint: Impacts on natural resources. FAO (Accessed on August 13, 2020) at: http://www.fao.org/3/i3347e/i3347e.pdf

Food and Agriculture Organization of the United Nations (FAO). 2014. Food Wastage Footprint: Full-cost accounting. FAO (Accessed on August 13, 2020) at: http://www.fao.org/3/a-i3991e.pd

Food and Agriculture Organization of the United Nations (FAO). 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against economic slowdowns and downturns. FAO (Accessed on August 13, 2020) at: http://www.fao.org/3/ca5162en/ca5162en.pdf

Food and Agriculture Organization of the United Nations: Statistics Division (FAOSTAT). 2015. Agriculture Database (Accessed on January 25, 2021) at: http://www.fao.org/faostat/en/#data

Fraiture, C.; Wichelns, D., 2010. Satisfying future water demands for agriculture. Agricultural Water Management, v. 97, (4), 502-511. https://doi.org/10.1016/j.agwat.2009.08.008

Freire Junior, M.; Soares, A.G., 2014. Orientações Quanto ao Manuseio Pré e Pós-Colheita de Frutas e Hortaliças Visando à Redução de suas Perdas. EMBRAPA (Accessed on August 13, 2020) at: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1003270/1/CT205finalizado.pdf

Fulton, J.; Norton, M.; Shilling, F., 2019. Water-indexed benefits and impacts of California almonds. Ecological Indicators, v. 96, part 1, 711-717. https://doi.org/10.1016/j.ecolind.2017.12.063

GBD 2016 Brazil Collaborators, 2018. Burden of disease in Brazil, 1990–2016: a systematic subnational analysis for the Global Burden of Disease Study 2016. The Lancet, v. 392, (10149), 760-775. https://doi.org/10.1016/S0140-6736(18)31221-2

Gerten, D.; Hoff, H.; Rockström, J.; Jägermeyr, J.; Kummu, M.; Pastor, A.V., 2013. Towards a revised planetary boundary for consumptive freshwater use: role of environmental flow requirements. Current Opinion in Environmental Sustainability, v. 5, (6), 551-558. https://doi.org/10.1016/j.cosust.2013.11.001

Gleeson, T.; Wang-Erlandsson, L.; Zipper, S.C.; Porkka, M.; Jaramillo, F.; Gerten, D.; Fetzer, I.; Cornell, S.E.; Piemontese, L.; Gordon, L.J.; Rockström, J.; Oki, T.; Sivapalan, M.; Wada, Y.; Brauman, K.A.; Flörke, M.; Bierkens, M.F.P.; Lehner, B.; Keys, P.; Kummu, M.; Wagener, T.; Dadson, S.; Troy, T.J.; Steffen, W.; Falkenmark, M.; Famiglietti, J.S., 2020. The water planetary boundary: interrogation and revision. One Earth, v. 2, (3), 223-234. https://doi.org/10.1016/j.oneear.2020.02.009

Godfray, H.C.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science, v. 327, (5967), 812-818. https://doi.org/10.1126/science.1185383

Gustavsson, J.; Cederberg, C.; Sonesson, U.; Emanuelsson, A., 2013. The methodology of the FAO study: "Global Food Losses and Food Waste-extent, causes and prevention". FAO (Accessed on August 13, 2020) at: https://www.diva-portal.org/smash/get/diva2:944159/FULLTEXT01.pdf

Gustavsson, J.; Cederberg, C.; Sonesson, U.; Van Otterdijk, R.; Meybeck, A., 2011. Global food losses and food waste: extent, causes and prevention. FAO (Accessed on August 13, 2020) at: https://reliefweb.int/sites/reliefweb.int/files/resources/FAO%20Report%202011%20%281%29.pdf

Hoekstra, A.Y.; Chapagain, A.K.; Aldaya, M.M.; Mekonnen, M.M., 2011. Manual de avaliação da pegada hídrica: Estabelecendo o padrão global. Instituto de Conservação Ambiental, São Paulo.

Hogeboom, R.J., 2020. The Water Footprint Concept and Water's Grand Environmental Challenges. One Earth, v. 2, (3), 218-222. https://doi.org/10.1016/j.oneear.2020.02.010

Instituto Brasileiro de Geografia e Estatística (IBGE). 2013. Projeções da População: 2013. IBGE (Accessed on January 25, 2021) at: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html?edicao=9116&t=resultados

Jaramillo, F.; Destouni, G., 2015. Local flow regulation and irrigation raise global human water consumption and footprint. Science, v. 350, (6265), 1248-1251. https://doi.org/10.1126/science.aad1010

Kibler, K.M.; Reinhart, D.; Hawkins, C.; Motlagh, A.M.; Wright, J., 2018. Food waste and the food-energy-water nexus: a review of food waste management alternatives. Waste Management, v. 74, 52-62. https://doi.org/10.1016/j.wasman.2018.01.014

Kummu, M.; De Moel, H.; Porkka, M.; Siebert, S.; Varis, O.; Ward, P.J., 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Science of the Total Environment, v. 438, 477-489. https://doi.org/10.1016/j.scitotenv.2012.08.092

Le Roux, B.; Van der Laan, M.; Vahrmeijer, T.; Annandale, J.G.; Bristow, K.L., 2018. Water Footprints of Vegetable Crop Wastage along the Supply Chain in Gauteng, South Africa. Water, v. 10, (5), 539. https://doi.org/10.3390/w10050539

Lipinski, B.; Hanson, C.; Lomax, J.; Kitinoja, L.; Waite, R.; Searchinger, T., 2013. Reducing food loss and waste. World Resources Institute (Accessed on August 13, 2020) at: https://pdf.wri.org/reducing_food_loss_and_waste.pdf

Liu, J.; Lundqvist, J.; Weinberg, J.; Gustafsson, J., 2013. Food losses and waste in China and their implication for water and land. Environmental Science & Technology, v. 47, (18), 10137-10144. https://doi.org/10.1021/es401426b

Lundqvist, J.; de Fraiture, C.; Molden D., 2008. Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain (Accessed on August 13, 2020) at: http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/5088/PB_From_Filed_to_Fork_2008.pdf?sequence=1&isAllowed=y

Mekonnen, M.M.; Hoekstra, A.Y., 2010a. The green, blue and grey water footprint of farm animals and animal products. UNESCO-IHE. v. 1 (Accessed on August 13, 2020) at: https://ris.utwente.nl/ws/portalfiles/portal/59481062/Report-48-WaterFootprint-AnimalProducts-Vol1.pdf

Mekonnen, M.M.; Hoekstra, A.Y., 2010b. The green, blue and grey water footprint of farm animals and animal products. UNESCO-IHE. v. 2 (Accessed on August 13, 2020) at: https://ris.utwente.nl/ws/portalfiles/portal/59481062/Report-48-WaterFootprint-AnimalProducts-Vol1.pdf

Mekonnen, M.M.; Hoekstra, A.Y., 2011a. National water Footprint accounts: the green, blue and grey water Footprint of production and consumption. UNESCO-IHE. v. 1 (Accessed on August 13, 2020) at: https://waterfootprint.org/media/downloads/Report50-NationalWaterFootprints-Vol1.pdf

Mekonnen, M.M.; Hoekstra, A.Y., 2011b. The green, blue and grey water footprint of crops and derived crop product. Hydrology and Earth System Sciences, v. 15, (5), 1577-1600. https://doi.org/10.5194/hess-15-1577-2011

Millennium Ecosystem Assessment, 2005. Relatório-Síntese da Avaliação Ecossistêmica do Milênio. MEA (Accessed on August 13, 2020) at: http://www.millenniumassessment.org/documents/document.446.aspx.pdf.

Munoz Castillo, R.; Feng, K.; Hubacek, K.; Sun, L.; Guilhoto, J.; Miralles-Wilhelm, F., 2017. Uncovering the green, blue, and grey water footprint and virtual water of biofuel production in Brazil: a nexus perspective. Sustainability, v. 9, (11), 2049. https://doi.org/10.3390/su9112049

Nouri, H.; Stokvis, B.; Galindo, A.; Blatchford, M.; Hoekstra, A.Y., 2019. Water scarcity alleviation through water footprint reduction in agriculture: The effect of soil mulching and drip irrigation. Science of the total environment, v. 653, 241-252. https://doi.org/10.1016/j.scitotenv.2018.10.311

Parfitt, J.; Barthel, M.; Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. Philosophical Transactions of the Royal Society B, v. 365, (1554), 3065-3081. https://doi.org/10.1098/rstb.2010.0126

Pavão, E.; Strumpf, R.; Martins, S., 2020. Cálculo da pegada de carbono e hídrica na cadeia da carne bovina no Brasil (Accessed on January 25, 2021) at: https://www.escolhas.org/wp-content/uploads/2020/01/Relatorio_Do-pasto-ao-prato_Pegadas_FINAL.pdf

Porkka, M.; Gerten, D.; Schaphoff, S.; Siebert, S.; Kummu, M., 2016. Causes and trends of water scarcity in food production. Environmental Research Letters, v. 11, (1), 015001. http://dx.doi.org/10.1088/1748-9326/11/1/015001

Porpino, G.; Parente, J.; Wansink, B., 2015. Food waste paradox: antecedents of food disposal in low income households. International Journal of Consumer Studies, v. 39, (6), 619-629. https://doi.org/10.1111/ijcs.12207

Read, Q.D.; Brown, S.; Cuéllar, A.D.; Finn, S.M.; Gephart, J.A.; Marston, L.T.; Meyer, E.; Weitz, K.A.; Muth, M.K., 2020. Assessing the environmental impacts of halving food loss and waste along the food supply chain. Science of The Total Environment, v. 712, 136255. https://doi.org/10.1016/j.scitotenv.2019.136255

Reddy, P.P., 2016. Sustainable intensification of crop production. Springer, Singapore.

Rocha, C.T.D.; Christofidis, D., 2015. Vantagens da opção pela agricultura irrigada. Revista de política agrícola, v. 24, (2), 17-25 (Accessed on August 13, 2020) at: https://seer.sede.embrapa.br/index.php/RPA/article/view/1007/949

Rockström, J.; Falkenmark, M.; Allan, T.; Folke, C.; Gordon, L.; Jägerskog, A. Kummu, M.; Lannerstad, M.; Meybeck, M.; Molden, D.; Postel, S.; Savenije, H.H.G.; Svedin, U.; Turton, A.; Varis, O., 2014. The unfolding water drama in the Anthropocene: towards a resilience based perspective on water for global sustainability. Ecohydrology, 7, (5), 1249-1261. https://doi.org/10.1002/eco.1562

Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin III, F.S.; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.; Nykvist, B.; de Wit, C.A.; Hughes, T.; Van Der Leeuw, S.; Rodhe, H.; Sörlin, S.; Snyder, P.K.; Costanza, R.; Svedin, U.; Falkenmark, M.; Karlberg, L.; Corell, R.W.; Fabry, V.J.; Hansen, J.; Walker, B.; Liverman, D.; Richardson, K.; Crutzen, P.; Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, v. 14, (2), 32 (Accessed August 13, 2020) at: http://www.jstor.com/stable/26268316

Rodrigues, D.B.; Gupta, H.V.; Mendiondo, E.M., 2014. A blue/green water-based accounting framework for assessment of water security. Water Resources Research, v. 50, (9), 7187-7205. https://doi.org/10.1002/2013WR014274

Rodrigues, P., 2017. Os desperdícios por trás do alimento que vai para o lixo. EMBRAPA (Accessed on August 13, 2020) at: https://www.embrapa.br/busca-de-noticias/-/noticia/28827919/os-desperdicios-por-tras-do-alimento-que-vai-para-o-lixo

Schyns, J.F.; Booij, M.J.; Hoekstra, A.Y., 2017. The water footprint of wood for lumber, pulp, paper, fuel and firewood. Advances in Water Resources, v. 107, 490-501. https://doi.org/10.1016/j.advwatres.2017.05.013

Schyns, J.F.; Hoekstra, A.Y.; Booij, M.J., 2015. Review and classification of indicators of green water availability and scarcity. Hydrology and Earth System Sciences, v. 19, (11), 4581-4608. https://doi.org/10.5194/hess-19-4581-2015

Schyns, J.F.; Hoekstra, A.Y.; Booij, M.J.; Hogeboom, R.J.; Mekonnen, M.M., 2019. Limits to the world's green water resources for food, feed, fiber, timber, and bioenergy. Proceedings of the National Academy of Sciences, v. 116, (11), 4893-4898. https://doi.org/10.1073/pnas.1817380116

Silva, V.D.P.R.; Oliveira, S.D.; Hoekstra, A.Y.; Dantas Neto, J.; Campos, J.H.B.; Braga, C.C.; Araújo, L.E.; Aleixo, D.O.; Brito, J.I.B.; Souza, M.D.; Holanda, R.M., 2016. Water footprint and virtual water trade of Brazil. Water, v. 8, (11), 517. https://doi.org/10.3390/w8110517

Spang, E.; Stevens, B., 2018. Estimating the Blue Water Footprint of In-Field Crop Losses: A Case Study of US Potato Cultivation. Sustainability, v. 10, (8), 2854. https://doi.org/10.3390/su10082854

Springer, N.P.; Duchin, F., 2014. Feeding nine billion people sustainably: conserving land and water through shifting diets and changes in technologies. Environmental Science & Technology, v. 48, (8), 4444-4451. https://doi.org/10.1021/es4051988

Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; Vries, W.; Wit, C.A.; Folke, C.; Gerten, D.; Heinke, J.; Mace, G.M.; Persson, L.M.; Ramanathan, V.; Reyers, B.; Sörlin, S., 2015. Planetary boundaries: Guiding human development on a changing planet. Science, v. 347, (6223), 1259855. https://doi.org/10.1126/science.1259855

Sun, S.K.; Lu, Y.J.; Gao, H.; Jiang, T.T.; Du, X.Y.; Shen, T.X.; Wu, P.T.; Wang, Y.B., 2018. Impacts of food wastage on water resources and environment in China. Journal of Cleaner Production, 185, 732-739. https://doi.org/10.1016/j.jclepro.2018.03.029

Trento, E.J.; Sepulcri, O.; Morimoto, F., 2011. Comercialização de Frutas, Legumes e Verduras. EMATER (Accessed on August 13, 2020) at: http://atividaderural.com.br/artigos/560455c4f123d.pdf

United Nations. 2019. Department of Economic and Social Affairs, Population Division (DESA). World Population Prospects 2019: Highlights (Accessed on August 13, 2020) at: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

Vanham, D.; Bouraoui, F.; Leip, A.; Grizzetti, B.; Bidoglio, G., 2015. Lost water and nitrogen resources due to EU consumer food waste. Environmental Research Letters, v. 10, (8), 084008. http://dx.doi.org/10.1088/1748-9326/10/8/084008

Vörösmarty, C.J.; McIntyre, P.B.; Gessner, M.O.; Dudgeon, D.; Prusevich, A., Green, P.; Bunn, S.E.; Sullivan, C.A.; Liermann, R.C.; Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature, v. 467, (7315), 555-561. https://doi.org/10.1038/nature09440

Xinchun, C.; Mengyang, W.; Rui, S.; La, Z.; Dan, C.; Guangcheng, S.; Xiangping, G.; Weiguang, W.; Shuhai, T., 2018. Water footprint assessment for crop production based on field measurements: A case study of irrigated paddy rice in East China. Science of the Total Environment, v. 610-611, 84-93. https://doi.org/10.1016/j.scitotenv.2017.08.011