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ASSESSING THE WATER FOOTPRINT OF NATIONAL CONSUMPTION FOR POLAND

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Abstract

The water footprint (WF) of national consumption is an indicator that takes into account both the direct (domestic water use) and indirect (water required to produce the products consumed) water use of consumers within a country. This study quantifies the water footprint of national consumption in Poland on national and regional levels. It tracks the consumptive use of rainwater (green WF) and ground and surface water (blue WF), and water pollution (gray WF). The total WF of national consumption in Poland in the 2006-2011 period was 53.6 Gm^3/yr (72% green, 10% blue, 18% gray). The average consumer in Poland had a WF of 1,400.5 m^3/yr. Agricultural goods provided the largest contribution to the WF of the average consumer (1,241.4 $m^3/cap/yr$), followed by industrial goods (145.6 $m^3/cap/yr$), and finally domestic water use (13.5 $m^3/cap/yr$). The assessment of the WF has formed a new interesting field for integrated geographical studies. It provides useful data for informing consumers about the environmental impacts of their lifestyle and consumption choices. In water policy, it can also create a basis for discussing water allocation and issues related to sustainable, equitable, and efficient water use.

Key words

consumption • virtual water • water • water footprint • Poland

Introduction

After years of debate, the interest in consumption-based environmental accounting significantly increased (Galli et al. 2012). Numerous studies, regardless of the methodology used in them, quantify consumer emissions in order to demonstrate the

environmental impacts of consumption (Nijdam et al. 2005; Weber & Matthews 2008; Davis & Caldeira 2010; Ewing et al. 2010; SEPA 2013). There is the approach, where all emissions occurring along the chains of production and distribution are allocated to the final consumers of products. This approach is seen as providing several opportunities for policy and decision-making processes (Wiedmann 2009). This approach also allows for the inclusion into environmental accounts of all driving forces for emissions associated with consumption. It also provides a useful communication tool. Such a tool can be used to inform consumers of their direct and indirect emissions associated with their lifestyles and consumption choices. The consumption-based approach identifies hot spots and unsustainable consumption patterns. Thus, this approach forms the basis for formulating strategies on sustainable consumption and production at the national, regional, and local levels.

In response to the need for a consumption-based indicator of freshwater use, the water footprint concept was introduced (Hoekstra & Hung 2002; Hoekstra ed. 2003). Introduced in the 1990s, the WF was developed similarly to the ecological footprint concept (Rees 1992; Wackernagel & Rees 1996; Wackernagel et al. 1997). While the 'ecological footprint' quantifies the area needed to sustain people's living, the 'water footprint' indicates the water required to sustain a population. The water footprint concept forms a new interesting field for integrated geographical studies. It is a concept which intrinsically combines aspects of natural and social conditions. In water policy, the WF accounts form a basis for discussing water allocation and issues related to sustainable, equitable, and efficient water use (Aldaya et al. 2010; Hoekstra & Mekonnen 2012a). The water footprint offers a wider perspective than traditionally used measures of water withdrawal. The actual water needs of people in relation to their consumption volume and pattern are described (Hoekstra & Chapagain 2007). In conjunction with the ecological and carbon footprints, WF is seen as a complement to traditional analyses of human demand by linking the producer and consumer perspectives (Galli et al. 2012). The European Union sees the potential of the WF as an operational tool of resource-efficient policy, as well as an indicator of ecosystem services connected with water quantity and quality (EC 2011; EP 2012). The aforementioned aspects are a very prospective field for methodological and application studies in geography, and provide guidance and direction on research issues.

As an indicator of human pressure on the hydrosphere, the WF looks at both the direct and indirect consumer use of water. The water footprint of national consumption is defined as the total volume of fresh water that is used to produce the goods and services consumed by the inhabitants of a country (Hoekstra et al. 2011). The water footprint can be presented as one aggregate number, but in fact, it is a multidimensional indicator of water use and shows different sorts of water consumption and pollution (Hoekstra et al. 2009). Three key water components are tracked in its calculation: the blue, green, and gray water footprint. The blue water footprint is related to the consumption of surface and ground water as a result of the production of a good. Consumption refers to the loss of water from the available ground-surface body of water in a catchment area, which takes place while water evaporates or is incorporated into a product. The green water footprint refers to the consumption of rainwater, stored in the soil as soil moisture, which is particularly relevant in crop production. The gray water footprint is related to water pollution and is defined as the volume of freshwater required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra et al. 2011).

The water footprint is closely linked to the concept of virtual water. The virtual water content of a product refers to the volume of water consumed or polluted for its production, and measured over its full production chain (Hoekstra et al. 2009). The concept

of virtual water was introduced by Allan in the early 1990s. It is used as a tool to describe the 'virtual' water flows exported from a region as a result of the export of water-intensive commodities (Allan 1993, 1994).

Global studies on the water footprints of countries were carried out by Hoekstra and Hung (2002), Chapagain and Hoekstra (2004), and Mekonnen and Hoekstra (2011). For some countries, detailed national studies were developed covering different aspects of the water footprint (Guan & Hubacek 2007; Aldaya et al. 2008; Gupta 2008; Liu & Savenije 2008; Sonnenberg et al. 2009; van Oel et al. 2009; Verma et al. 2009; Bulsink et al. 2010; Yu et al. 2010; Feng et al. 2011; Destatis 2012; Vanham 2013a). There also exist the first assessments of water footprints for the European Union (Steen-Olsen et al. 2012; Vanham & Bidoglio 2013; Vanham et al. 2013), for river basins (Zeng et al. 2012; Vanham 2013b), and for cities (Hoff et al. 2013).

Research conducted in Poland in the field of water footprint accounting, is in the exploratory stages. To the best knowledge of the author, the only Polish work dedicated to the development of WF assessment in practice, is a study on the water footprint of regional consumption for the Wielkopolska region (Stępniewska 2012). This is the first study that has focused on the quantification of the water footprint of consumption in Poland at the national level and the establishment of regional diversity. The total water footprint is seen as divided into direct and indirect components. Within each of the components, the assumed aim was to determine the blue, green, and gray components, taking into account water source and water pollution.

Material and Methods

Study area

From 2006 to 2011, the Polish population consisted of 38.3 million people living in an area of 312.7 thousand km^2. The regional diversity of the water footprint of national consumption was divided into 16 voivodeships, and examined. The total WF of consumption was divided between different voivodeships based on population statistics. In the period from 2006 to 2011, the most populated regions in the country were the Mazowieckie (5.2 million people), Śląskie (4.6 million people), Wielkopolskie (3.4 million people), and Małopolskie (3.3 million people) voivodeships.

Accounting framework

This paper (like most of the existing WF studies) is based on the approach developed by the Water Footprint Network (Hoekstra et al. 2011).

The total water footprint of national consumption (WF_{cons}, in m^3/yr) is calculated by adding the direct water footprint of consumers to two indirect water footprint components:

$$WF_{cons} = WF_{cons,dir} + WF_{cons,indir}\,(\text{agricultural commodities}) + WF_{cons,indir}\,(\text{industrial commodities})$$

The direct water footprint of national consumption ($WF_{cons,dir}$) refers to the consumption and pollution of water related to the domestic water supply. The indirect water footprint of consumers ($WF_{cons,indir}$) refers to the water usage by others to make the consumed commodities, with the agricultural and industrial commodities differentiated.

An overview of data sources used for WF accounting is given in Table 1. The source materials are a combination of statistics and data from the literature.

Direct water footprint

The blue water footprint within the country that is related to domestic water supply, is estimated assuming that 10% of water withdrawals is the actual consumption (blue water footprint) (Mekonnen & Hoekstra 2011). The remaining fraction (return flow to the catchment) is the non-consumptive part of water withdrawals and as such, it is not part of the water footprint.

Table 1. Data sources used within the paper for water footprint accounting

Data	Period	Data source
Population [cap]	2006-2011	CSO (2006-2011)
Water withdrawal [m^3/yr]	2006-2011	CSO (2006-2011)
Population not served by sewage treatment plants [cap]	2006-2011	CSO (2006-2011)
Consumption values for agricultural products [ton/yr]	2006-2011	FAOSTAT(2006-2011)
The blue, green, and gray water footprints of agriculture products [m^3/ton]	1996-2005	Mekonnen & Hoekstra (2010a,b)
The blue, and gray water footprint of consumption of industrial products [m^3/yr/cap]	1996-2005	Mekonnen & Hoekstra (2011)

The part of the return flow, which is disposed of into the environment without prior treatment, is taken as a measure of the gray water footprint. The amount of raw sewage is estimated on the basis of the population not served by sewage treatment plants and the average domestic water consumption per inhabitant in individual voivodeships.

Indirect water footprint

The total water footprint of the consumption of agricultural products [$WF_{cons,indir}$ (agricultural commodities)] is calculated by multiplying the set of agricultural products consumed within the country by the respective water footprints of their products:

$$WF_{cons,indir}(\text{agricultural commodities}) = \sum (C[p]) \times WF_{prod}[p])$$

C[p] is the consumption of agricultural product *p* by the inhabitants of the country (tons/yr), and WF_{prod} [p] is the water footprint of this product (m^3/ton). The following range of final agricultural goods is considered:

- livestock products – butter, milk, yoghurt, cheese, eggs, pork, poultry;
- cereal products – wheat, barley, rye, oat, rice, pasta;
- vegetables – potatoes, tomatoes, onions, beans, peas;
- fruit – apples, bananas, grapefruit, oranges, mandarins, lemons, limes, pineapples, grapes;
- oil crops – ground nuts, coconuts, olives;
- oil from oil crops – soya bean oil, ground nut oil, sunflower seed oil, rape and mustard oil, palm oil;
- sweeteners – sugar (raw equivalent);
- coffee, tea, cocoa beans;
- beverages – beer, wine.

The water footprint of the consumption of industrial products can be calculated in a similar manner as was earlier described for agricultural products. However, there are numerous categories of industrial products with varying production methods. Detailed standardised statistics related to the production and consumption of these products are hard to find. For this reason, the study was based on the data about the blue and gray water footprints of the industrial product consumption per capita in Poland, presented by Mekkonen and Hoekstra (2011). The mentioned global study contains national water footprint accounts carried out in the configuration of states in a high-spatial resolution. The international trade of products was taken into account. For industrial commodities, the authors calculated the water footprint of national consumption as the water footprint of industrial processes taking place within the nation, plus the import virtual water related to the imports of industrial commodities minus export virtual water. The national average water footprint per dollar of industrial product was calculated per country by dividing the total national water footprint in the industrial sector by the value added in the industrial sector. In the case of exported products, the authors adopted

the respective average water footprint per tonne of product in the exporting nation.

The values of the green, blue, and gray WFs of agricultural and industrial products, provided by Mekonnen and Hoekstra (2011), are recommended for analyses by UNESCO-IHE Institute for Water Education and by Water Footprint Network. The majority of prepared assessments of the WF of national consumption for regions and countries, are based on these data. There are single, more recent studies on the WF of products, which include few products based on varied methodologies and a time and space range. The use of WF values of products from the Mekonnen and Hoekstra study (2011) ensures the consistency of the methodology and the possibility of making international comparisons.

Results and Discussion

Direct water use: Water footprint of domestic water consumption

The total water footprint of domestic water consumption in Poland from 2006 to 2011 was 515.8 million m^3 (23% blue, 77% gray). The blue water footprint was about 120.5 million m^3, which was only slightly more than 2.0% of the total blue WF of national consumption. The highest values of the blue WF of domestic water consumption were recorded in the Mazowieckie (19.0 million m^3/yr), Śląskie (14.2 million m^3/yr), Wielkopolskie (12.1 million m^3/yr), and Dolnośląskie (9.3 million m^3/yr) voivodeships. It was associated with the highest water abstraction of households in these voivodeships. The gray water footprint of domestic water consumption in Poland from 2006 to 2011, was approximately 395.3 million m^3/yr. The highest values were found in the Mazowieckie (84.0 million m^3), Wielkopolskie (40.7 million m^3), Śląskie (37.7 million m^3), and Małopolskie (35.6 million m^3) voivodeships. Against the background of the country, the voivodeships were characterised by the highest number of residents discharging wastewater into the environment without prior treatment (a total of 6.7 million).

Indirect water use: Water footprint of the consumption of agriculture and industrial products

The total water footprint of the agricultural product consumption in Poland in the period from 2006 to 2011 was 47.5 Gm^3/yr (82% green, 9% blue, 9% gray). The water footprint due to the consumption of agricultural products can be specified into product categories (Tab. 2). Consumption of livestock products gives the largest contribution to the total WF of the agricultural product consumption (56%), followed by cereals (21%), and coffee, tea, and cocoa beans (6%). The remainder of the footprint is related to other agricultural products (17%).

In the territorial division, the highest value of the total WF of the agricultural product consumption from 2006 to 2011, was found in the Mazowieckie (6.5 Gm^3/yr), Śląskie (5.8 Gm^3/yr), Wielkopolskie (4.2 Gm^3/yr), and Małopolskie (4.1 Gm^3/yr) voivodeships. These are the most populated regions of the country, where the highest total consumption values for agricultural products were reported.

The total national water footprint related to the consumption of industrial products in the time period from 2006 to 2011 was 5.6 Gm^3/yr (11% blue, 89% gray). It was calculated assuming the value of the blue and gray WF per capita, respectively 15.4 m^3/yr and 130.2 m^3/yr (Mekkonen & Hoekstra 2011). The highest values of the total WF consumption of industrial products were found in the Mazowieckie (760.5 million m^3/yr), Śląskie (676.3 million m^3/yr), Wielkopolskie (496.8 million m^3/yr), and Małopolskie (480.9 million m^3/yr) voivodeships.

The total water footprint of national consumption

The total water footprint of national consumption from 2006 to 2011, was 53.6 Gm^3/yr (72% green, 10% blue, 18% gray). Regional disparities of the total WF and its blue, green, and gray components are presented in Table 3. Slightly more than half

Table 2. Water footprint (WF) of consumers related to the consumption of agricultural products in Poland, in the period 2006-2011 (million m^3/yr)

Product category	Green WF [mln m^3/yr]	Blue WF [mln m^3/yr]	Gray WF [mln m^3/yr]	Total WF [mln m^3/yr]	Total WF [%]
Livestock products	22,551.5	1,996.9	2,249.9	26,798.3	56.41
Cereal products	7,598.6	1,549.4	1,056.1	10,204.2	21.48
Coffee, tea, cocoa beans	2,804.0	38.8	84.4	2,927.1	6.16
Oil from oil crops	1,818.4	98.0	155.8	2,072.2	4.36
Vegetables	1,239.8	229.5	400.8	1,870.0	3.94
Sweeteners	872.2	272.3	264.1	1,408.5	2.96
Fruit	658.3	155.3	131.9	945.6	1.99
Beverages	957.8	69.6	107.3	1,134.7	2.39
Oil crops	134.2	7.3	5.1	146.5	0.31
Total	38,634.7	4,417.1	4,455.3	47,507.2	100.00

(50.9%) of the total WF of national consumption is attributable to five voivodeships: Mazowieckie (7.3 Gm^3/yr), Śląskie (6.5 Gm^3/yr), Wielkopolskie (4.8 Gm^3/yr), Małopolskie (4.6 Gm^3/yr), and Dolnośląskie (4.0 Gm^3/yr).

The average consumer in Poland, from 2006 to 2011, had a total water footprint of 1,400.5 m^3/yr. An overview of the individual contribution of consumption categories to the water footprint of national consumption is given in Figure 1. Agricultural goods are responsible for the largest part of the total WF (1,241.4 m^3/cap/yr), followed by industrial goods (145.6 m^3/cap/yr), and domestic water use (13.5 m^3/cap/yr).

A comparison of the WFs of national consumption in Poland in the years from 1996 to 2005, and from 2006 to 2011, with values of these indices for EU countries, is presented in Table 4. The analysis was based on the results of the global water footprint study by Mekonnen and Hoekstra (2011). This study contains the more comprehensive and up-to-date data on the WF of nations, covering a several-year-long research period. As the same method and assumptions are applied in this study, it is possible to directly compare the results.

From 1996 to 2005, the total WF of national consumption in Poland was 1405.4 m^3/capita/year. This value was slightly higher than the total WF for the world (1,385.2 m^3/capita/year). The average value of this indicator for the European Union was 1,836.2 m^3/capita/year; as a result, Poland ranked 25th among the member states. There are no results of research for the European Union which cover a later period; however, this research shows that the total WF for Poland decreased slightly (by less than 0.5%) over the next five-year period. However, significant changes in its structure occurred. An increase in the number of people using water treatment

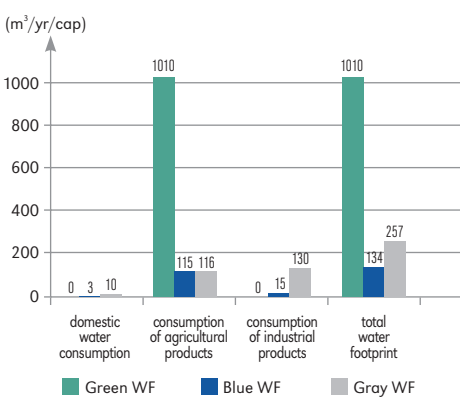

Figure 1. The water footprint of the national consumption per capita in Poland from 2006 to 2011, shown by the major consumption categories

Table 3. The water footprint (WF) of national consumption in Poland, from 2006 to 2011 by voivodeships (million m^3/yr)

Voivodeship	WF of domestic water consumption		WF of consumption of agricultural products			WF of consumption of industrial products		Total WF of national consumption			
	Blue	Gray	Green	Blue	Gray	Blue	Gray	Green	Blue	Gray	Total
Dolnośląskie	9.3	20.3	2,919.0	333.7	336.6	44.5	376.5	2,919.0	387.6	733.4	4,039.9
Kujawsko-pomorskie	6.8	19.1	2,097.6	239.8	241.9	32.0	270.5	2,097.6	278.7	531.5	2,907.8
Lubelskie	5.8	24.7	2,188.8	250.2	252.4	33.4	282.3	2,188.8	289.4	559.4	3,037.6
Lubuskie	3.1	9.2	1,023.4	117.0	118.0	15.6	132.0	1,023.4	135.7	259.2	1,418.3
Łódzkie	8.9	27.5	2,572.5	294.1	296.7	39.2	331.8	2,572.5	342.3	656.0	3,570.8
Małopolskie	8.8	35.6	3,334.8	381.3	384.6	50.9	430.1	3,334.8	440.9	850.3	4,625.9
Mazowieckie	19.0	84.0	5,273.2	602.9	608.1	80.4	680.1	5,273.2	702.4	1,372.2	7,347.7
Opolskie	3.0	10.0	1,038.9	118.8	119.8	15.8	134.0	1,038.9	137.7	263.8	1,440.3
Podkarpackie	4.7	16.9	2,129.0	243.4	245.5	32.5	274.6	2,129.0	280.6	537.0	2,946.5
Podlaskie	3.7	12.3	1,207.2	138.0	139.2	18.4	155.7	1,207.2	160.1	307.2	1,674.4
Pomorskie	7.5	13.4	2,258.6	258.2	260.5	34.5	291.3	2,258.6	300.1	565.2	3,123.9
Śląskie	14.2	37.7	4,689.6	536.2	540.8	71.5	604.8	4,689.6	621.9	1,183.3	6,494.8
Świętokrzyskie	3.2	14.1	1,288.7	147.3	148.6	19.7	166.2	1,288.7	170.2	328.9	1,787.7
Warmińsko-mazurskie	4.4	11.3	1,449.3	165.7	167.1	22.1	186.9	1,449.3	192.3	365.4	2,007.0
Wielkopolskie	12.1	40.7	3,444.9	393.9	397.3	52.5	444.3	3,444.9	458.5	882.2	4,785.6
Zachodniopomorskie	6.0	16.6	1,719.2	196.6	198.3	26.2	221.7	1,719.2	228.8	436.6	2,384.6
Total	120.5	395.3	38,634.7	4,417.1	4,455.3	589.3	4,982.6	38,634.7	5,127.0	9,833.3	53,594.9

Table 4. The water footprint (WF) of national consumption per capita in EU countries in the time period from 1996 to 2005 (m^3/capita/year) according to Mekonnen & Hoekstra (2011)

Country	Total WF of national consumption			
	Green	Blue	Gray	Total
Luxembourg	1,941.2	103.5	469.6	2,514.3
Portugal	1,854.2	363.2	288.1	2,505.5
Spain	1,802.1	321.2	338.0	2,461.3
Cyprus	1,682.3	349.3	353.8	2,385.4
Hungary	1,916.3	65.7	401.8	2,383.8
Greece	1,652.0	326.0	360.1	2,338.1
Italy	1,720.5	192.7	389.8	2,303.0
Bulgaria	1,809.2	82.6	405.0	2,296.8
Malta	1,674.8	206.7	334.3	2,215.8
Slovenia	1,345.6	97.2	569.5	2,012.3
Belgium	1,215.7	142.2	529.6	1,887.5
Latvia	1,326.5	64.1	406.2	1,796.8
France	1,353.4	135.2	297.0	1,785.6
Estonia	1,314.4	156.5	248.8	1,719.7
Romania	1,344.8	76.7	267.3	1,688.8
Croatia	1,355.0	37.7	295.0	1,687.7
Czechia	1,236.7	79.7	334.2	1,650.6
Denmark	1,222.1	95.5	317.0	1,634.6
Austria	1,134.4	98.7	364.4	1,597.5
Lithuania	1,266.7	54.4	194.8	1,515.9
The Netherlands	1,055.9	128.9	280.9	1,465.7
Sweden	1,038.1	80.0	309.6	1,427.7
Germany	1,053.3	85.1	287.8	1,426.2
Finland	1,057.2	79.5	277.2	1,413.9
Poland	1,010.6	58.8	336.0	1,405.4
Poland 2006-2011 (present study)	1,009.5	134.0	257.0	1,400.5
Slovakia	1,014.3	73.4	247.7	1,335.4
Ireland	939.6	108.7	253.2	1,301.5
United Kingdom	915.5	92.7	249.8	1,258.0
UE-28	1,366.2	134.1	336.9	1,836.2
The World	1,015.4	153.3	216.5	1,385.2

plants was accompanied by a decrease in the gray WF by more than 1/5. At the same time, there was an over two-fold increase in the blue WF.

The water footprint of national consumption depends on the volume of consumption, the consumption pattern, and the water footprints of the consumed commodities (Hoekstra & Chapagain 2007). The latter depend on the production conditions in the places of origin of individual commodities. Products available for purchase within a country gen-

erally come from different places, and having different production circumstances are characterised by different WFs. In this study, global averages of the WFs for each product were used. Further research should include the specification of products consumed in Poland according to places of origins. This will determine the WFs of consumed products with greater precision. It will also enable us to identify how much of the impact of WF on national consumption is located in the country and how much abroad. Many countries have a significantly externalised water footprint (Hoekstra & Mekonnen 2012b). The result is their dependency on water resources from elsewhere, which can cause potential water stress - water depletion or pollution - in the producing countries.

As an aggregated indicator, WF shows the total water requirement of inhabitants. Water footprint is an approximate measure of the impact of human consumption on the water environment. However, some practical limitations and challenges associated with WF assessment should be borne in mind. The critical issues are data availability, and more reliability. It should also be noted, that the gray WF calculation relies heavily on assumptions and estimations. In contrast to the blue and green water concepts, the gray WF is not an indicator of water use, but an indicator of water pollution. Some authors suggest that the expression of the environmental impact of water pollution by turning water quality into water quantity results in the loss of important information. This is because such factors as ecotoxicity and biodegradability of individual pollutants, are ignored (Hastings & Pegram 2012). In this paper, the size of the gray WF of national consumption is expressed in terms of the sewage disposed of into the environment without prior treatment. It should be seen as a very conservative calculation, with a potentially underestimated value. Generally, one cubic meter of wastewater should not count for one, as it pollutes many more cubic meters of water after disposal (Hoekstra & Chapagain 2007). Another approach involves estimating water volumes required to assimilate the load of different types of pollutants, e.g. nitrogen or phosphorus, as in the Liu et al. study (2012). However, depending on the considered pollutant, the quality of data, and adopted water quality standards, the gray WF can differ considerably. For these reasons, the gray WF methodology needs to be further developed and standardised (Thaler et al. 2012).

Conclusions

The study shows the effect of consumption on water requirement in Poland. The results indicate the dominant role of indirect water use – fresh water consumption and pollution 'behind' products being consumed by inhabitants. In my paper, it was found that the consumption of agricultural products, particularly of livestock products and cereals, contributes the most to the total water footprint of Poland. The direct use of water is only a small part of the total fresh water use. These results confirm the potential of water footprint accounts to supplement the traditional approach, based only on the water-withdrawal indicators. With the release of both direct and indirect water pressures associated with consumption, a useful tool is provided for informing consumers of all environmental impacts of the consumer consumption choices. The results may also provide a basis for discussing water allocation and issues related to sustainable, equitable, and efficient water use at the national and regional levels. Key limitations and challenges with the use of this approach to individual objectives, include data availability, and more reliability as well as dealing with methodological difficulties in calculating the gray water footprint.

Editors' note: Unless otherwise stated, the sources of tables and figures are the author's on the basis of their own research.

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