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Blue Water Footprint of the Czech Republic

Xuexiu Jia[a,*], Jiří Jaromír Klemeš[a], Petar Sabev Varbanov[a], Sharifah R Wan Alwi[b]

[a]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic
[b]Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
jia@fme.vutbr.cz

Water scarcity has been a serious concern as a global issue in various regions around the world. Located in the central Europe, the Czech Republic is also affected by the shortage of water. To improve the understanding of water use at a country level and identify the potential for optimal water management, this study investigated the internal blue water footprint of the Czech Republic from 2013 to 2017 and the national blue water footprint in 2017. Based on the existing method, treated water and water loss, as the water recharged to natural water supply, are considered as an offset of the water footprint. The results showed a slight increase in the internal blue water footprint in 2013 - 2017. The national blue water footprint showed that fossil fuel and paper are the two major imported commodities contributing to virtual water import, and wheat and beer are the major commodities contributing to virtual water export in 2017.

1. Introduction

Water scarcity has become a severe issue as a result of increasing water consumption and degradation. Even in regions and countries such as Central Europe and the Czech Republic, drought has become an issue concerned by the decision makers and scientific research (State Land Office, 2019). A study (Data.Brno, 2018) claimed that the Czech Republic went through the driest summer season in 2018. A series of satellite images of the second largest city in the Czech Republic, Brno, showed that the soil moisture content in the city had reduced obviously in three years from 2015 to 2018. The drought affects not only the agriculture but also the climate, their study also showed the city has become hotter in the three years, and the region is 3.8 °C higher than the average of years from 1981 to 2010 (Data.Brno, 2018).

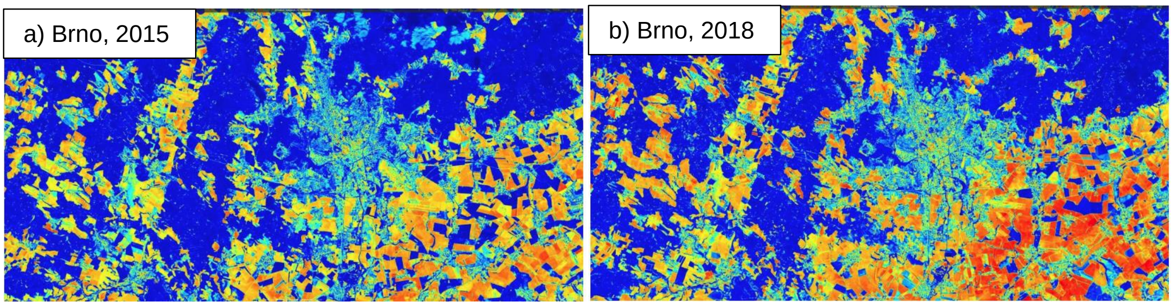
a) Brno, 2015
b) Brno, 2018

Figure 1: Satellite-derived soil moisture content of Brno, the Czech Republic in a) Aug. 2015 and b) Aug. 2018 (Data.Brno, 2018)

Human activity plays an essential role in the occurrence of water scarcity. The increase of population, industry and trade, as well as over-consuming/wasting can increase the water demand. While low water returns and high water pollution would decrease the usability of the water supply. In addition, the policy and pricing system of water resource can also affect the water demand and use at a large scale. It is important to investigate the water

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use patterns to better understand the national water flows, in order to identify the potentials for the solutions for regional water scarcity issues. As a widely used indicator, water footprint (WF) (Hoekstra, 2003) is helpful to represent the water consumption and track the virtual water flow in international trade. As a consumption-based water use indicator, the concept and methodology of WF have been well investigated and improved by the team (Hoekstra et al., 2011) and others (Zhuo et al., 2016). Water footprint assessment (WFA) has been widely implemented at various levels including product (Schyns and Vanham, 2019), sectors (Hoekstra, 2015), regions (Vanham, 2018), as well as the national level (Steen-Olsen et al., 2012). The original water footprint on a national level is applied to improve the understanding of the relative significance of a country's impacts in a global perspective, and shed light on the poetntial drivers of these impacts. On the other hand it can only provide limited information for the national water resources management. In this study, WFA method is modified to benchmark the water use from an input-output perspective, to provide supportive results for water resources management. The blue water footprint of the Czech Republic is carried out as a case study to illustrate the implementation of the method. This is made necessary by the current water scarcity issues of the Czech Republic and a lack of water use information at the national level. The ultimate goal of this study is to benchmark the overall internal and external virtual water consumptions of the country, and consequently track the water use pattern and identify the potential for optimal water management. The novelty of the study is 1) providing a different interpretation of the WFA in terms of national water resources management, and 2) modifying the WFA method of including water return and recalculating external virtual water footprint. By calculating the water footprint stemming from the national territory and identifying the critical production paths and final demand products, and the results can identify potentials for national water optimisation.

2. Methods and data sources

2.1 National water footprint assessment

Chapagain and Hoekstra (2004) initiated the research report determining the water footprint of the nation. The water footprint of a nation [m^3/y] includes the internal water footprint (IWFP) and the external water footprint (EWFP), as shown in Eq(1).

$$WFP = IWFP + EWFP \tag{1}$$

where *WFP* is the national water footprint [m^3/y]. *IWFP* is the Internal Water Footprint [m^3/y], represents the total volume of water used, directly or indirectly, to produce the goods and services consumed by the inhabitants of the country. *EWFP* is the External Water Footprint [m^3/y], represents water embodied in the products imported from abroad and consumed in the current country. The IWFP and EWFP are calculated as Eq(2) and Eq(3).

$$IWFP = AWU + IWW + DWW - VWE_{dom} = TWW - VWE_{dom} \tag{2}$$

where *AWU* is the agricultural water consumption [m^3/y], *IWW* and *DWW* are the industrial and domestic water withdrawals [m^3/y], *TWW* is the total water withdrawal [m^3/y]. VWE_{dom} is the volume of the virtual water embodied in the domestically produced products that are exported to other countries [m^3/y].

$$EWFP = VWI - VWE_{re-export} \tag{3}$$

VWI is the virtual water import [m^3/y], and $VWE_{re-export}$ is the virtual water exported to other countries as a result of the re-export of imported products [m^3/y].
The virtual water footprint of the product *p* from exporting country *e* to the importing country *i* is calculated as Eq(4).

$$VWF(e,i,p) = PT(e,i,p) \times VWC(e,p) \tag{4}$$

where, *PT* is the product trade [t/y] from exporting country *e* to importing country *i*, and *VWC* is the virtual water content [m^3/t] of product *p* in the exporting country.
In Eq(2), VWE_{dom} is deducted from IWFP to avoid the double counting of the part included in the industrial and/or agricultural water consumption. However, it is challenging to extract the re-export product data from overall export data. In this study, the $VWE_{re-export}$ and VWE_{dom} are aggregated as the international trade water footprint (TWFP) to replace EWFP, as shown in Eq(5).

$$TWFP = VWI - \left(VWE_{re-export} - VWE_{dom}\right) = VMI - VME \tag{5}$$

where *TWFP* is an international trade virtual water footprint [m^3/y]. *VWE* is the virtual water embodied in the product exported from the Czech Republic to other countries [m^3/y]. In addition, the water discharged from the Wastewater Treatment Plant (WWTP) and water loss during transportation, which is returned to the natural water supply, are deducted from the total water withdrawal (TWW) as an offset of the water footprint Eq(6).

$$IWFP = TWW - TW - WL \tag{6}$$

Where, *TW* is the treated water (including rainwater) from WWTPand *WL* is the pipeline water loss [m^3/y]. Both of which are returned to the natural water supply.
In order to provide results for future cross-border comparison, it would be helpful to calculate the water footprint per capita, which is the national water footprint divide by the population.

2.2 System boundary and data sources

Figure 2 shows the system boundary of the WFA. The inventory water flow includes domestic water use (agriculture, residential and industry), water recharges from WWTP to natural water bodies and virtual water during international trade. The water evaporation and transpiration are not considered due to the lack of data. Focusing on the water use flow, only the blue water footprint (Hoekstra, 2003) is assessed in this study.

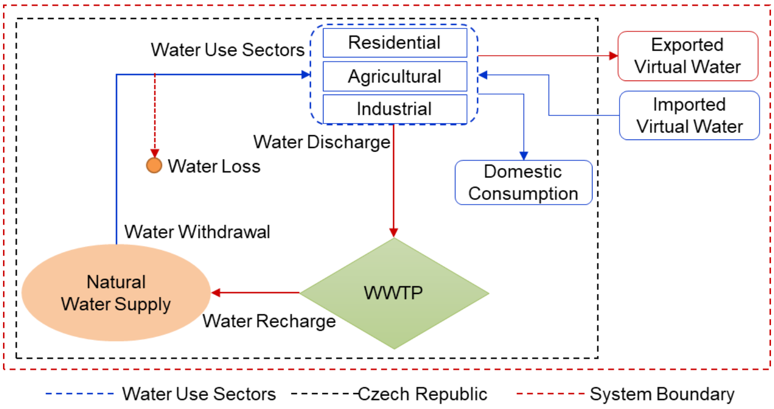

Figure 2: System boundary of the water footprint assessment in the Czech Republic

The domestic water consumption data, including the sectoral water absorption and water discharge, are extracted from the report on water management of the Czech Republic (MACR and MECR, 2018). The international trade data used to calculate the virtual water flow, are extracted from the database of the Czech Statistical Office (2019a). The mid-year population of the Czech Republic from 2013 to 2015 is 10.5 M, and from 2016-2017 is 10.6 M (2019b). Other data sources are marked where mentioned. Based on the selected data, the national WF is calculated for the year of 2017, and the internal WF is calculated from 2013 - 2017.

3. Water footprint inventory

3.1 Internal water flows

The internal water consumption covers the water withdrawal from natural water supply (agricultural, industrial, and residential) and water discharge and loss, as shown in Table 1, derived from MACR and MECR (2018).

Table 1: Water withdrawal, recharge and loss in the Czech Republic (2017), [Mm^3/y]

Year	Total water withdrawal (TWW)	Treated water (TW)	Water loss (WL)
2013	1,630	912	106
2014	1,638	812	96
2015	1,585	779	99
2016	1,625	803	90
2017	1,642	826	98

The treated water, including rainwater and the water loss in pipelines, is considered as the water recharged to the natural supply and would be deducted from the domestic water consumption, as an offset of internal water footprint.

3.2 International trade data of selected commodities

From the External Trade database of the Czech Statistical Office (2019a), 16 commodities are selected from the top 7 categories of exported and imported commodities based on the traded weight for the external water footprint calculation, as shown in Table 2.

Table 2: Selected imported and exported commodities in the Czech Republic in 2017 (based on weight)

No.	Import Commodities	Weight [Mt]	Imported country	Export Commodities	Weight [Mt]
1	Coal	3.71	PL	Pallets collars of wood	0.66
2	Conventional oil	8.05	PL, GE, AT	Coal	2.31
3	Lignite	0.13	PL	Conventional oil	0.83
4	Natural gas	6.63	GE	Lignite	0.98
5	Unalloyed steel	1.50	PL, GE, SK	Natural gas	0.47
6	Portland cement	0.03	AT	Unalloyed steel	1.80
7	Pallets collars of wood	0.21	PL	Beer	0.47
8	Polyesters	0.34	GE, SK	Bottled water	0.38
9	Paper/paper board	0.08	GE, SK	Portland cement	0.56
10	Unalloyed steel	0.09	GE	Wheat	1.44
11				Barley	0.48
12				Maize	0.37
13				Oats	0.04
14				Rye	0.03
15				Unalloyed steel	0.20
16				Polyesters	0.01

The virtual water contents (VWC) of the products are collected and presented in Table 3.

Table 3: VWC of traded commodities in the Czech Republic in 2017 [m^3/t]

Commodity	VWC	Reference	Commodity	VWC	Reference
Coal	4.20	Mekonnen et al., 2015	Steel	6.10	Bosman, 2016
Conventional oil	4.62		Beer	300	Hoekstra, 2008
Lignite	0.72		Bottled water	17.4	Tandon et al., 2014
Natural gas	1.70	Gerbens-Leenes et al., 2018	Wheat	342	Mekonnen and Hoekstra, 2011
Portland cement	0.51	Bosman, 2016	Barley	79.0	
Pallets	41.0	Schyns et al., 2017	Maize	81.0	
Polyesters	50.7	Freitas et al., 2017	Oats	181	
Paper	616	van Oel and Hoekstra, 2010	Rye	25.0	

4. Results and discussion

The internal water footprint and per capita value of the Czech Republic in 2013-2017 is calculated (Figure 3). From 2013 to 2017, the internal water footprint (IWFP) of the Czech Republic has the lowest value in the year 2013 (600 Mm^3/y), increasing to 718 Mm^3/y in 2014 (19.6 %) and maintained at a stable level around 700 m^3/y. The significant contribution is the water recharge increase, means more water is returned to the natural water supply. The average IWFP per capita is 65.2 m^3/capita/y, which is much lower than the average water consumption of 157 m^3/capita/y by Hunkar (2017). The difference is that the original WFA does not count the water returned to the natural water supply, and their results are higher.

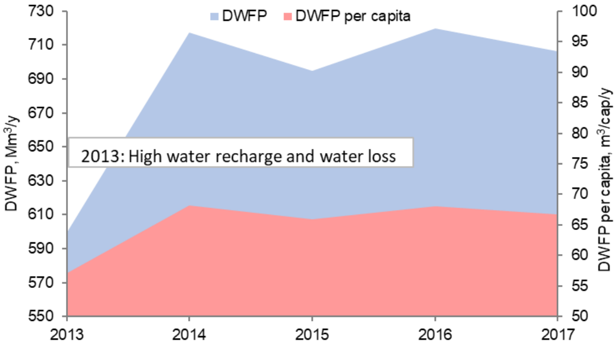

Figure 3. IWFP and per capita value of the Czech Republic from 2013 to 2017

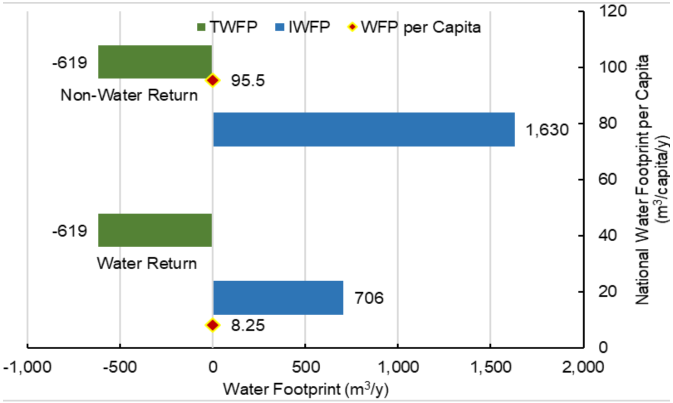

Figure 4. Breakdown of the national water footprint of the Czech Republic in 2017

The national water footprint of the Czech Republic with selected commodities is 87.4 Mm^3/y and is lower than the result of Chapagain and Hoekstra (2004), 636 Mm^3/y. A reason is that water discharge (water recharged to the natural water supply) offsets part of the water footprint. Another is due to the different selections of international trade products. Figure 4 showed the breakdowns of the national water footprint of the Czech Republic in 2017. The virtual water footprint from international trade (TWFP) is -619 Mm^3/y in 2017, the negative value indicates a net water export (the virtual water exported to other countries is more than imported from other countries). Fuel (coal, oil, natural gas, etc.) contributes the most (43.0 %) to the virtual water import, the following is paper, with a contribution of 33.2 %. Wheat contributes 63.9 % to the virtual water export (63.9 %) with a larger mass and high virtual water content, and the following is beer with a contribution of 18.3 %. When water recharge is considered, the blue water footprint per capita of the Czech Republic is 8.25 m^3/capita/y. The blue WFP per capita increase to 95.5 m^3/capita/y when exclude the water recharge. The value is about 27 % higher than the blue WFP of the Czech Republic (75 m^3/capita/y) in 2012 (Steen-Olsen et al., 2012), which covers the production and trade of primary products of agriculture and forestry in the country.

It is evident that the selections of traded commodities, data availability and quality can affect the result in a large extent. This indicates a need to discuss the role and contribution of water footprint assessment. The methodology for WFA should be specified when used for different aims and scope. The previously existing method for WFA is a effective tool for global environmental impact quantification. There is a need for the future efforts to improve the methodology to facilitate national and regional water resources management and provide insights to mitigate water scarcity. Future directions of WFA include 1) a comprehensive assessment of volumetric consumption and and water quality degradation, 2) water integration within the system boundary, and the extension of efforts in WFA using mathematical programming methods by Avison et al. (2011), and 3) water-energy nexus footprinting methods development and implementation.

5. Conclusions

This study determined the internal water footprint of the Czech Republic from 2013 to 2017, and the overall national water footprint of 2017. The main conclusions are i) The internal water footprint of the Czech Republic increased from 600 Mm^3/y to 706 Mm^3/y in the five years and maintained at around 700 Mm^3/y from 2014 – 2017. ii) the national water footprint per capita is 8.25 m^3/capita/y, and iii) Fossil fuel (coal, oil, natural gas, etc.) and paper are the major contributors to virtual water import, and wheat and beer are the significant contributors to the virtual water export. Recommendations derived from the studies are: i) Increase the water return, including water discharge, and rainwater collection can offset the water footprint increase. ii) The impact of importing water-intensive commodities should be further investigated, mainly agricultural products (e.g. crops, beer, etc.). and iii) There is a need to extend the water use database to more accurate assessment. Future efforts should be taken to identify the most important virtual water flows out of the country. Mathematical Programming based methods can be further investigated for water footprint optimisation.

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