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GREY WATER FOOTPRINT OF POINT SOURCES OF POLLUTION: CZECH REPUBLIC STUDY

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Abstract: Grey Water Footprint is an indicator of anthropogenic pollution load into the inland water. The indicator is used for quantification of water needed for pollutant dilution to such an extent that the quality of the ambient water remains above agreed water quality standards of pollution discharged from point sources in the Czech Republic. Grey Water Footprint was calculated for 6 382 point pollution sources, recorded in the national register of wastewater discharges, from period 2009–2018. The domestic, industry and agriculture sectors were analyzed separately in the assessment. The total Grey Water Footprint of point sources of pollution varied between 1.90×10^{10} and 2.46×10^{10} m^3/year. The Grey Water Footprint of domestic pollution represented about ¾ of the total Grey Water Footprint. The Grey Water Footprint of industrial pollution represented about ¼ of the total Grey Water Footprint. The Grey Water Footprint of agricultural point sources of pollution can be neglected on the national level in the Czech Republic. In most cases, the Grey Water Footprint is determined by ammonium nitrogen (NH_4-N).

Keywords: Czech Republic, Grey Water Footprint, point sources, pollution

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INTRODUCTION

Global population growth, social-economic changes and climate change will increase the stress to water resources (Vörösmarty *et al.*, 2000). Protecting freshwater resources requires diagnosing threats over a broad range of scales, from global to local (Vörösmarty *et al.*, 2010). Dealing with anthropogenic pollution of freshwater is one of the main challenges of the current world. Water pollutions is in many ways interlinked with Sustainable Development Goals declared by United Nations (Alcamo, 2019). Anthropogenic water pollution usually consist of three types of pollution a) agricultural, b) industrial and c) domestic (Ge *et al.*, 2011). Agricultural water pollution is mainly caused by diffuse pollution from farm land caused by fertilizer and pesticide utilization. Industrial and domestic water pollution are mainly caused by wastewater discharges from sewerage systems and wastewater treatment plants or by direct pollution loads from factories and households.

As the pressures on water resources increase, efforts to assess the impacts associated with water use are increasing. The "Water Footprint" (WF) has emerged as one tool for quantifying this impact (Fulton *et al.*, 2014). The WF concept was introduced in 2002 (Hoekstra, 2003) and consists from three parts (Hoekstra *et al.*, 2011). Blue WF represents fresh water withdraw from surface water and groundwater, which is consumend (not returned to the water body). Green WF represents precipitation which does not form surface water, groundwater and is reserved in a soil. Grey Water Footprint (GWF) represents the volume of water that is required to assimilate pollution; it is quantified as a volume of water needed to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards.

The WF as a methodology is very popular in last few years. It leads to increasing number of WF studiess published in literature (Mubako, 2018; Ansorge *et al.*, 2019; Zhu *et al.*, 2019) Unfortunately, some WF studies are only stated, that the GWF was omitted from the study due to different reasons (e.g. Lin *et al.*, 2017)

The GWF is often calculated in agriculture, where the GWF forms a part of the total Water Footprint assessment and the modelling approach is used for estimation of Green, Grey and Blue WF (e.g. Severo Santos & Naval, 2020).

A most studies in all sectors are focused on one pollutant, typically there are studies focused on nitrogen (e.g. Aldaya *et al.*, 2020) and phosphorus (e.g. Mekonnen & Hoekstra, 2018). Few studies are focused on several pollutants (Qin *et al.*, 2019; Stejskalová *et al.*, 2019; Yu *et al.*, 2019).

The WF assessment is sometimes joined with other footprint assessments (e.g. Feng & Zhao, 2020).

This study is focused on the GWF of pollution discharged into rivers, lakes and aquifers from point sources. In this filed of study, it has been published the GWF study of pharmaceuticals (Martínez-Alcalá *et al.*, 2018; Wöhler *et al.*, 2020), wastewater discharging from winery industry (Johnson & Mehrvar, 2019).

MATERIALS AND METHODS

Grey Water Footprint

GWF is calculated as maximal value of GWF of individual pollutants by **Eq. (1)**:

$$GWF = \max\{GWF_1, GWF_2, \ldots, GWF_i\} \qquad (1)$$

GWF for pollutants from point sources is calculated by **Eq. (2)**:

$$GWF_i = \frac{L_i}{c_{max,i} - c_{nat,i}} \qquad (2)$$

Where: L_i = pollutant *i* load
$c_{max,i}$ = the maximum acceptable concentration of the substance of *i* in the receiving water
$c_{nat,i}$ = the natural concentration of the substance of *i* in the receiving water

Pollutant load L_i is calculated by **Eq. (3)**:

$$L_i = Effl \times c_{effl,i} - Abstr \times c_{act,i} \qquad (3)$$

Where: *Effl* = effluent volume
$c_{effl,i}$ = the concentration of the pollutant *i* in the effluent
Abstr = water volume of the abstraction
$c_{act,i}$ = actual concentration of the pollutant *i* in the intake water

Water pollution is caused primarily by agricultural, industrial, and municipal sources (Qin *et al.*, 2019). Distinguishing between pollution sources leads to **Eq. (4)**:

$$GWF = GWF_{dom} + GWF_{ind} + GWF_{agri} \qquad (4)$$

where: GWF_{dom} = domestic Grey Water Footprint, GWF_{ind} = industrial Grey Water Footprint, GWF_{agri} = agricultural grey water footprint.

Study area

The Czech Republic belongs to the inland countries situated in the Central Europe (see **Fig. 1**). The most territory lies between latitudes 48° and 51° N, and longitudes 12° and 19° E. Altitude of most of the territory ranges between 200 and 600 m a.s.l. The Czech Republic lies in a temperate climate zone in the northern hemisphere, the average air temperature is 8 °C and the average precipitation amount is 693 mm (MoA, 2015). The Czech Republic lies at the watershed of three seas – the North Sea, the Baltic Sea and the Black Sea. Water resources of the Czech Republic are entirely dependent


Fig. 1 The Czech Republic in Europe (source: Wikipedia.org)

on atmospheric precipitation, because only approximately between 3 and 5 % of water runoff from the Czech Republic is coming from abroad.

The results of the assessment of the ecological status/potential and chemical status of water for the period 2013 to 2015 show good status only for 9.0 % water body in category "river" and 6.5 % water body in category "lake" (Tušil *et al.*, 2018). Discharges of municipal and industrial wastewater were included among the significant impacts for which exemptions from achieving good status according to the European Water Framework Directive (2000/60/EU) should be laid down in the Czech Republic (Prchalová *et al.*, 2017).

Data about pollutant load

In the Czech Republic, all subjects discharging wastewater must have a water authority permit to discharge pollutants into the water. Data about effluent volume exceeding statutory limits (500 m^3/month or 6 000 m^3/year) are recorded in the register of withdrawals and discharges (Ansorge *et al.*, 2016). In this register, there are recorded information about polluter, economic activity code (NACE), effluent volume (wastewater discharged into the rivers), concentration of the selected pollutant in the influent (wastewater discharged into sewerage systems) and in the effluent, localization and some others. The pollutantion parameters involved in the register are biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{Cr}), total inorganic nitrogen (TIN), ammonium nitrogen (NH_4-N), total phosphorus (TP), suspended solids (SS) and dissolved inorganic salts (DIS).

Data about pollutant concentration in the intake water are also in the national register of withdrawals and discharges. The complexity of water supply systems in the Czech Republic is very high and there is missing deep information about connections of water withdrawals places and water discharging places. Due this lack of information, we expected $Abstr \times c_{act} = 0$ and **Eq. (3)** was simplified to **Eq. (5)**:

$$L_i = Effl \times c_{effl,i} \tag{5}$$

For each record (place of discharge) and pollutant, the WF was calculated according to **Eq. (2)**.

Identifier NACE was used for distinguishing between wastewater discharged from public sewage systems (domestic sector) and from other anthropogenic activities (industry, services, agriculture etc.). This division is not fully correct because the majority of public sewerage systems treat wastewater from combined sewerage (from households andother anthropogenic activities), together with storm water runoff. A ratio between sewage from households and other anthropogenic activities pollution treated on municipal wastewater treatment plants (WWTPs) is about 2:1 (see **Table 1**). Data from last decade (period 2009–2018) was used in the study. The number of records analysed in the study is 47 272 (see **Table 2**). These records represent 6 382 pollution point resources.

Assimilation capacity

Maximum acceptable concentrations (c_{max}) of pollutants in a recipient water body are set by the Czech Technical

Table 1. Wastewater treated on WWTPs in the Czech Republic

	Sewage	Industry and other	Stormwater runnof
2009	37%	19%	44%
2010	33%	16%	51%
2011	36%	18%	46%
2012	37%	18%	45%
2013	35%	14%	51%
2014	36%	17%	47%
2015	37%	18%	45%
2016	37%	18%	46%
2017	36%	17%	46%
2018	40%	20%	40%

Table 2. Number of wastewater discharging records

	Domestic	Industry	Agriculture
2009	3 216	1 132	14
2010	3 287	1 141	13
2011	3 408	1 168	15
2012	3 528	1 187	17
2013	3 497	1 212	15
2014	3 536	1 218	16
2015	3 676	1 195	17
2016	3 729	1 149	17
2017	3 775	1 136	17
2018	3 798	1 121	18

Standard ČSN 75 7221 *Water quality - Classification of surface water quality* for II. water quality class. Natural concentration values (c_{nat}) were used from the same technical standard for I. water quality class. The difference between the values of maximum acceptable concentration (c_{max}) and natural concentration (c_{nat}) is described as water assimilation capacity (Jamshidi, 2019). The values of assimilation capacity used in this study are shown in **Table 3**.

RESULTS AND DISCUSSIONS

GWF from point sources of pollution in the Czech Republic varies between 1.90×10^{10} and 2.42×10^{10} m^3/year (see **Table 4)**. The main component of GWF is domestic GWF which represent from 73 to 78 %. Industrial GWF represents from 22 to 27 % of the total GWF caused by point sources of pollution. The Czech Republic is an industrial country and agriculture plays a marginal role in Czech economy. This is also reflected in the size of the agricultural GWF which represents less than 0.22 % of total GWF caused by point sources of pollution (see **Fig. 2**). These ratios are similar to those in other places such China (Zhang *et al.*, 2019). On the other hand, China is more agricultural country and agricultural GWF is higher than in the Czech Republic.

The most important determinants of GWF are ammonium nitrogen (NH_4-N) and total phosphorus (TP) (see **Fig. 3**). These 2 substances determinetes GWF between 83 and 92 % of pollution discharged in the Czech Republic. More interesting is the size and the structure of the GWF in individual sectors. Domestic GWF varies between 1.47×10^{10} and 1.76×10^{10} m^3/year and main pollutants which determinates the GWF is ammonium nitrogen (NH_4-N) and total phosphorus (TP) (see **Fig. 4**). These two pollutants determine the GWF most often due to very low assimilation capacity of these two substances. All other substances play marginal role in determination of domestic GWF (see **Table 3**).

Table 3. Assimilation capacity for pollutants [mg/L]

BOD	COD	TIN	NH4-N	SS	TP	DIS
2	10	2,8	0,2	10	0,1	150

Table 4. GWF in the Czech Republic [m^3/year]

	Domestic	Industrial	Agricultural	Total
2009	1.63×10^{10}	5.83×10^{9}	2.86×10^{7}	2.21×10^{10}
2010	1.76×10^{10}	6.53×10^{9}	3.46×10^{7}	2.42×10^{10}
2011	1.66×10^{10}	5.13×10^{9}	3.50×10^{7}	2.18×10^{10}
2012	1.54×10^{10}	4.73×10^{9}	1.93×10^{7}	2.01×10^{10}
2013	1.62×10^{10}	5.56×10^{9}	2.70×10^{6}	2.17×10^{10}
2014	1.47×10^{10}	4.87×10^{9}	4.86×10^{6}	1.96×10^{10}
2015	1.53×10^{10}	4.84×10^{9}	4.77×10^{6}	2.01×10^{10}
2016	1.48×10^{10}	4.23×10^{9}	6.92×10^{6}	1.90×10^{10}
2017	1.68×10^{10}	4.98×10^{9}	3.98×10^{6}	2.18×10^{10}
2018	1.55×10^{10}	4.64×10^{9}	4.38×10^{6}	2.01×10^{10}

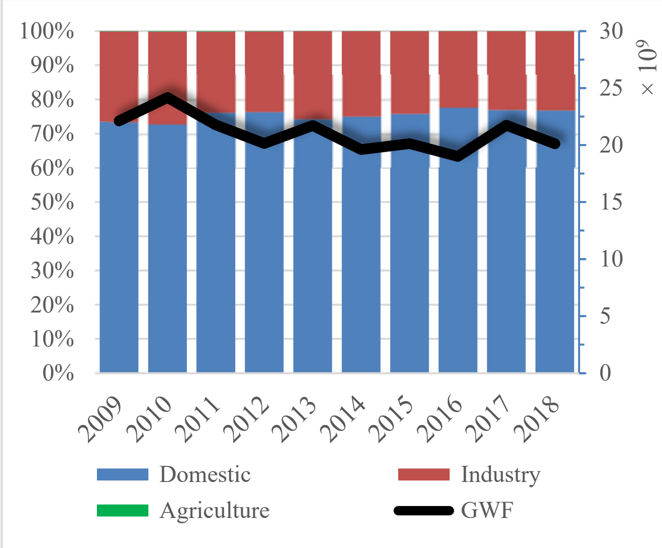

Fig. 2 GWF in the Czech Republic and its components

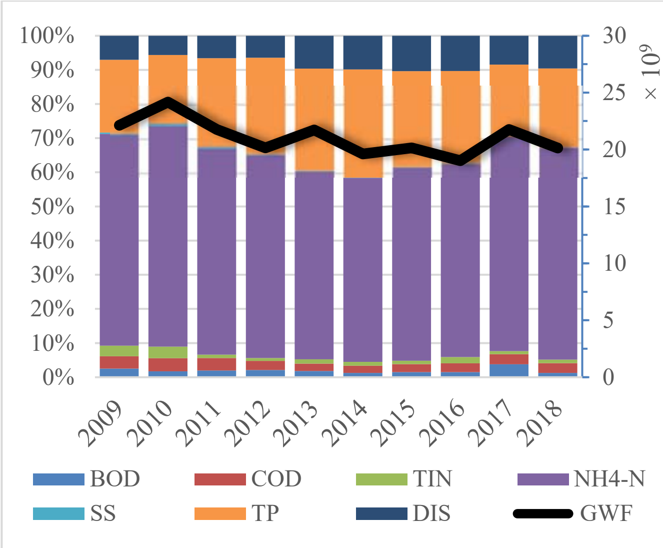

Fig. 3 Total GWF in the Czech Republic and its determinants

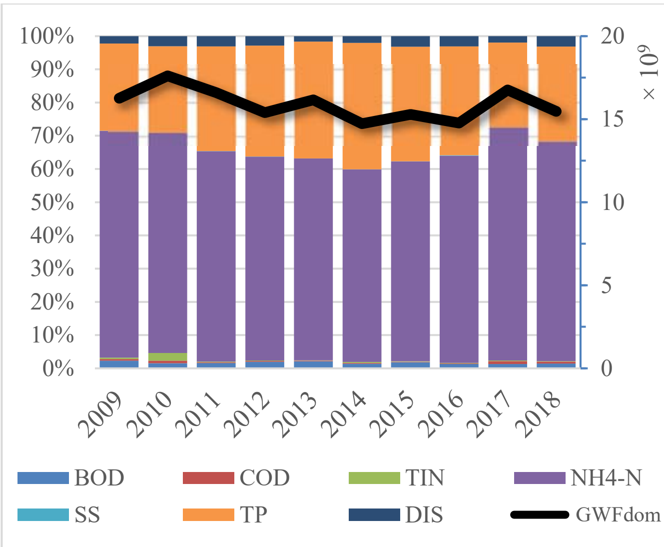

Fig. 4 Domestic GWF in the Czech Republic and its determinants

The industrial GWF varies between 4.23×10^9 and 6.53×10^9 m^3/year and the main pollutant which determinate the GWF is also ammonium nitrogen (NH_4-N). The second main pollutant is a parameter of dissolved inorganic salts (DIS), but also other substances (except suspended solids) determine the water footprint by 10 percent or more percent in individual years (see **Fig. 5**).

The agricultural GWF varies between 2.70×10^6 and 3.50×10^7 m^3/year (see **Fig. 6**) and the main pollutant which determinates the GWF is also ammonium nitrogen (NH_4-N), but only in 7 of 10 years. Agriculture is an only sector, where dissolved inorganic salts (DIS) does not determine the GWF. There is also no second main pollutant. On the other hand, there are only few records in the national register (see **Table 2**).

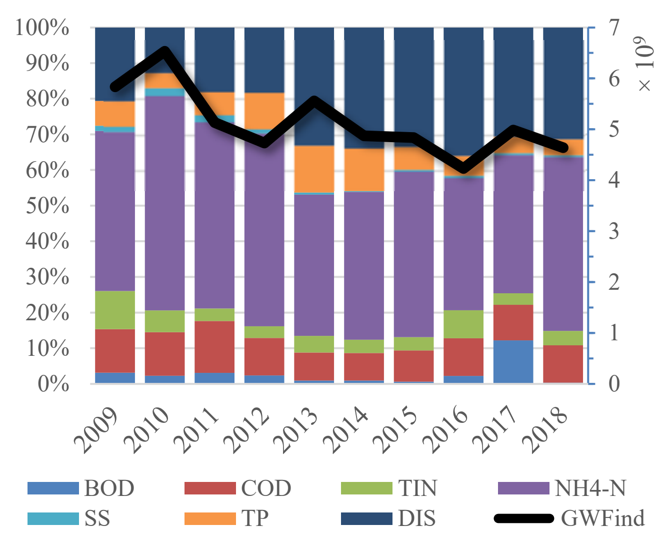

Fig. 5 Industrial GWF in the Czech Republic and its determinants

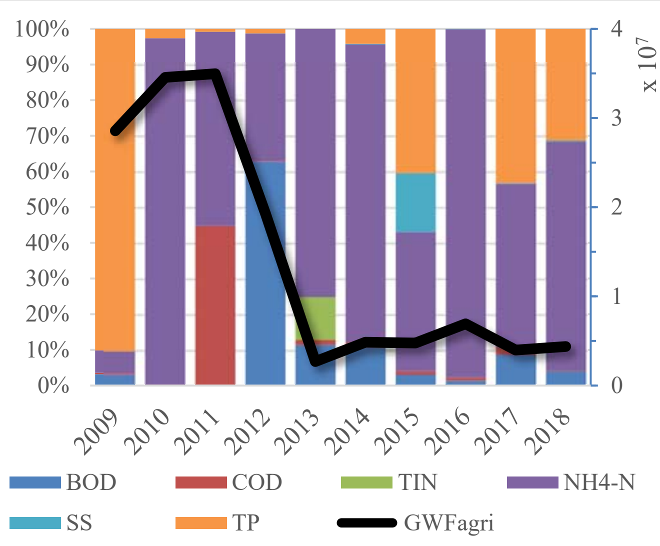

Fig. 6 Agricultural GWF in the Czech Republic and its determinants

CONCLUSIONS

The study showes that the GWF from point sources of pollution in the Czech Republic varies between 1.90×10^{10} and 2.46×10^{10} m^3/year in period 2009–2018. The domestic GWF represents about ¾ of the total GWF from point sources of pollution. The industrial GWF represents approximately ¼ of the total GWF from point sources of pollution. Due to very low assimilation capacity, the GWF in all three sectors is caused by the parameter of NH_4-N. The parameter of total phosphorus is the second most importantsubstance causing the GWF, especially in the domestic sector. The trend of domestic GWF is very slowly decreasing. In the industrial sector, there are also important parameters of DIS, TP and COD. The trend of the GWF is decreasing. Pollution from point sources of pollution in the agricultural sector is not important in the Czech Republic. There are less than 20 points of discharge in the agricultural sector recorded in the register of discharges and the agricultural GWF can be neglected in the global assessment. The period 2009–2018 can be divided into two parts. In 2009–2013, there can be seen a rapid decrease of the agricultural GWF from about 3.5×10^7 m^3/year to approximately 4.6×10^6 m^3/year (in the period 2013–2018).

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