New Approach to Municipal Grey Water Footprint Estimation: A Case Study for Aegean Region Cities in Turkey

Hülya Boyacıoğlu

Department of Environmental Engineering, Faculty of Engineering, Tinaztepe Campus, Dokuz Eylül University, Turkey

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Abstract This study aimed to develop an approach to investigate grey water footprint-GWF of municipalities in the Aegean Region in Turkey. In this scope 8 out of 81 cities were analyzed in terms of their waste water production (volume), waste water treatment (type of treatment, waste water receiving media etc.) in the country. Data was handled, within the series of waste water official surveys at a municipal level published annually/bi-annually by the National Institute of Statistics (TUIK) since 2001. “Total Nitrogen TN” has been selected as a reference variable for GWF calculations. The required additional data/information for the calculations was natural/background nitrogen concentrations, maximum allowable nitrogen concentrations for water bodies. Grey water footprint was calculated for each single city and then spatial differences were determined. Study results revealed that GWF was changeable from one city to another (450-1150 m³/ca.yr). Higher GWF (treated) amount compared to the GWF (un-treated) in some regions was explained by higher volume of treated wastewater. Observation of relatively high values for GWF (treated) in some places was due to type of water treatment processes. Availability of N removal process at treatment plants was major impact on low GWF value. It can be concluded that GWF could be indicator to investigate effectiveness of wastewater management strategies, and determine its environmental effects.

Keywords GWF Grey Water Footprint, Natural Background Concentration, Maximum Allowable Concentration

1. Introduction

The water footprint is an indicator of human appropriation of freshwater resources. It measures both the

direct and indirect “water use” of consumers and producers. The term “water use” refers to two different components: consumptive water use (of rainwater—the green water footprint and of surface and groundwater- the blue water footprint) and degenerative water use (the Grey water footprint).

The Grey water footprint (GWF) is an indicator of the water volume needed to assimilate a pollutant load that reaches a water body. As an indicator of water resources appropriation through pollution, it provides a tool to help assess the sustainable, efficient and equitable use of water resources. The advantage of expressing water pollution in terms of the water volume required for assimilating the pollutants, rather than in terms of concentrations of contaminants, is that this brings water pollution into the same unit as consumptive use [1, 2, 3].

Recent studies mostly focused on the industrial and agricultural production [4, 5, 6]. This study will be one of the pioneer research focusing on municipal grey water footprint.

2. Study Area

The study area covers nearly one-eighth of the Anatolian Peninsula (of Turkey) and is located approximately within the latitudes 36°00'–40°00' N and the longitudes 26°00'–31°00' E (Fig. 1). The region has a Mediterranean climate with annual mean precipitations ranging from 450 to 1200 mm/yr [7]. Population served by sewage system and annual discharged wastewater per capita is presented in Table 1.

3. Study Method

In the study “Total Nitrogen TN” has been selected as a reference variable for GWF calculations and anthropogenic nitrogen (N) loads to freshwater was estimated for each

city in the region. Data was handled, within the series of waste water official surveys at a municipal level published annually/bi-annually by the National Institute of Statistics (TUIK) since 2001 [5]. The estimated pollutant load generated by the municipalities was based on information for the year 2014.

Table 1. Population served by sewage system and discharged water as of 2014 [8]

City	Population (as of 2014)	Water discharges (dm ³ /ca.day)
İzmir	3825157	214
Manisa	1258473	122
Aydın	937781	181
Denizli	782960	198
Muğla	626156	361
Afyonkarahisar	497721	154
Kütahya	424493	192
Uşak	233763	148

Figure 1. Aegean Region Cities

Grey Water Footprint: The Grey water footprint (GWF, m³/ca.yr) is calculated by dividing the N load (Load, kg/ca.yr) by the difference between the ambient water quality standard for N (the maximum acceptable concentration C_{max} , mg/L) and the natural concentration of N in the receiving water body (C_{nat} , in mg/L):

$$GWF = \frac{Load}{(C_{max} - C_{nat})}$$

The natural concentration in a receiving water body (C_{nat}) is the concentration in the water body that would occur if there were no human disturbances in the catchment. For human-made chemical substances that naturally do not

occur in water, C_{nat} is zero. When natural concentrations are not known precisely but are estimated to be low, for simplicity one may assume C_{nat} is also zero. However, when C_{nat} is actually not equal to zero, this results in an underestimated GWF, because the assimilation capacity for the chemical substance would be overestimated [2]. For the natural background concentrations, local data are suggested to be used. If local data are not available and time and budget do not allow determining the natural background concentrations, the values in the literature could be used.

Regarding the maximum allowable concentrations in ambient water bodies, “The Water Footprint Assessment Manual” suggests to use local ambient water quality standards. However, for comparative studies, in which GWF estimates for different locations are to be compared, it is recommended to take the same standards throughout the study. Regarding the maximum allowable concentrations in ambient water bodies, these guidelines suggest to select the strictest standard as used in the European Union, the United States or Canada. These standards are up to date and scientifically most reliable [2].

In the literature there are different values for maximum allowable and natural concentrations. For this study, the maximum acceptable value provided by the GWF guidelines, 2.96 mg N/L, which is based on the guideline for the protection of aquatic life as proposed by the Canadian Council of Ministers of the Environment was used [9]. The same guidelines from the Water Footprint Network suggest a natural concentration value for total N of 0.38 mg N/L, which is close to the average natural concentration of N in rivers of 0.375 mg N/L reported by Meybeck [10] (see Table 2 and 3).

Table 2. Maximum allowable concentration of nutrients [after 2]

Nutrients	Maximum allowable concentration µg/L
Ammonia - NH ₃	19 NH ₃
Nitrate NO ₃	13000 NO ₃
Nitrite NO ₂	60 NO ₂ -N

Table 3. Natural/background concentrations nutrients [after 2]

Nutrients	Natural/background concentrations (mg/L)
Ammonium N-NH ₄	0.015
Nitrate N-NO ₃	0.1
N organic	0.26

“Load (m³/ca.yr)” was calculated by adding together the treated pollutant load and untreated pollutant load. For this calculation following classes were created for each city.

- Untreated wastewater amount (m³/ca. yr.)
- Treated wastewater amount (m³/ca.yr). (classified according to the following treatment type)
 - Untreated wastewater
 - Secondary treatment
 - Physical treatment
 - Advanced treatment (nutrient removal)

Based on the treatment level, concentration of C was estimated (see Table 4) and this value was multiplied by amount of wastewater to determine load (kg/ca.yr).

$$L = C \times Q$$

Table 4. Typical effluent quality for various levels of treatment [after 11 and 12]

Treatment process	Total N (mg/L)
Untreated wastewater	60
Secondary treatment	30
Physical treatment	40
Advanced treatment (nutrient removal)	15

4. Results and discussion

GWF ($\text{m}^3/\text{ca.yr}$), population served by sewage system and waste water discharges ($\text{m}^3/\text{ca.yr}$) values for each cities are presented in Table 5. Spatial distribution of water discharges and GWF is depicted on the maps that were created using Arc Map 10.3.1 (see Fig 2 through 5).

From Table 4, it is concluded that not only the

wastewater amount but also treatment level has impact on GWF. Thus GWF from discharged waste water, treated wastewater and untreated wastewater for each city was calculated and results are shown in Fig. 3-5.

The outcomes of the study revealed that:

- Annual waste water discharges per capita showed difference mainly between 40-80 $\text{m}^3/\text{ca.yr}$ except Muğla. This value was 130 $\text{m}^3/\text{ca.yr}$ in this city and high touristic activities is considered as a reason for this extreme amount.
- GWF was also changeable from one city to another (450-1150 $\text{m}^3/\text{ca.yr}$). Lowest value was observed for “İzmir” where %100 of the municipal water is treated.
- Higher GWF (treated) compared to the GWF (un-treated) in some regions was explained by higher treatment rate of wastewater
- Observation of relatively high values for GWF (treated) in some regions was explained by type of water treatment processes. Availability of N removal process at treatment plants was also major impact on low GWF value.

Table 5. GWF of cities ($\text{m}^3/\text{ca.yr}$)

City	Population served by sewage system (as of 2014)	Water discharges ($\text{m}^3/\text{ca.yr}$)	GWF ($\text{m}^3/\text{ca.yr}$)
İzmir	3825157	78.1	451
Manisa	1258473	44.5	1145
Aydın	937781	66.1	774
Denizli	782960	72.3	971
Muğla	626156	131.8	1688
Afyonkarahisar	497721	56.2	702
Kütahya	424493	70.1	854
Uşak	233763	54.0	492

Figure 2. Grey water footprint of study region

Figure 3. Amount of discharged municipal waste water

Figure 4. GWF from discharged wastewater (un-treated)

Figure 5. GWF from discharged wastewater (treated)

5. Conclusions

This study aimed to develop an approach to investigate grey water footprint of municipalities in the Aegean Region in Turkey. In this scope 8 out of 81 cities were analyzed in terms of their waste water production (volume), waste water treatment (type of treatment, waste water receiving media etc.) in the country. “Total Nitrogen TN” has been selected as a reference variable for GWF calculations. The required additional data/information for the calculations was natural/background nitrogen concentrations, maximum allowable nitrogen concentrations for water bodies. Grey water footprint was calculated for each single city and then spatial differences were determined. Based on the results it was concluded that GWF was changeable from one city to another and with the range of 450-1150 m³/ca.yr. Higher GWF for treated compared to the un-treated wastewaters in some regions was explained by higher treated amount of wastewater (in volume). Observation of relatively high values for GWF (treated) in some places was due to type of water treatment processes. Availability of N removal process at treatment plants was major impact on low GWF value. In summary GWF could be indicator to investigate effectiveness of wastewater management strategies, and determine its environmental effects.

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