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

**Boyacıoğlu H.**

Dokuz Eylul University Faculty of Engineering Department of Environmental Engineering Tinaztepe Campus Buca 35390 Izmir, Turkey.

email: hulya.boyacioglu@deu.edu.tr

**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 $m^3$/ca.yr). 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 places was due to type of water treatment processes. Availability of N removal process at treatment plans 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

## 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 (Mekonnen and Hoekstra, 2015; Franke et. al, 2013).

The earlier studies mostly focused on the sector (industry, agriculture etc) and this will be one of the pioneer research focusing on municipal grey water footprint.

## Study area

The study area covers nearly one-eighth of the Anatolian Peninsula (of Turkey) and is located approximately within the latitudes 368000 –408000 N and the longitudes 268000 –318000 E (Fig. 1). The region has a Mediterranean climate with annual mean precipitations ranging from 450 to 1200 mm/yr (Aşikoğlu and Çiftlik, 2015). Population served by sewage system and annual discharged wastewater per capita is presented in Table 1.

## 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 cities 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 (Turkish Statistical Institute, 2017). 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 (Turkish Statistical Institute, 2017)

| City | Population (as of 2014) | Water discharges ($m^3$/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, $m^3$/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 Cmax, mg/L) and the natural concentration of N in the receiving water body (Cnat, in mg/L):

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

It should be noted that the natural concentration is the concentration in a water body if it were in pristine condition, before human disturbances in the catchment. 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. 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 (see Table 2 and 3).

**Table 2.** Maximum allowable concentration of nutrients (after Franke *et al*, 2013)

| 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 Franke *et al*, 2013)

| 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 classess were created for each city.

- ✓ Untreated wastewater amount ($m^3$/ca. yr.)
- ✓ Treated wastewater amount ($m^3$/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 x Q

**Table 4.** Typical effluent quality for various levels of treatment (after MoEF, 2010 and Metcalf & Eddy, 1991)

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

**Results and discussion**

GWF($m^3$/ca.yr), population served by sewage system and waste water discharges ($m^3$/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).

**Table 5** GWF of cities ($m^3$/ca.yr)

| City | Population served by sewage system (as of 2014) | Water discharges (m3/ca.yr) | GWF (m3/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 |

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 is shown in Fig. 3-5.

The outcomes of the study revealed that:

- Annual waste water discharges per capita showed difference mainly between 40-80 $m^3$/ca.yr except Muğla. This value was 130 $m^3$/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 $m^3$/ca.yr). Lowest value was observed for "Izmir" 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 plans was also major impact on low GWF value.

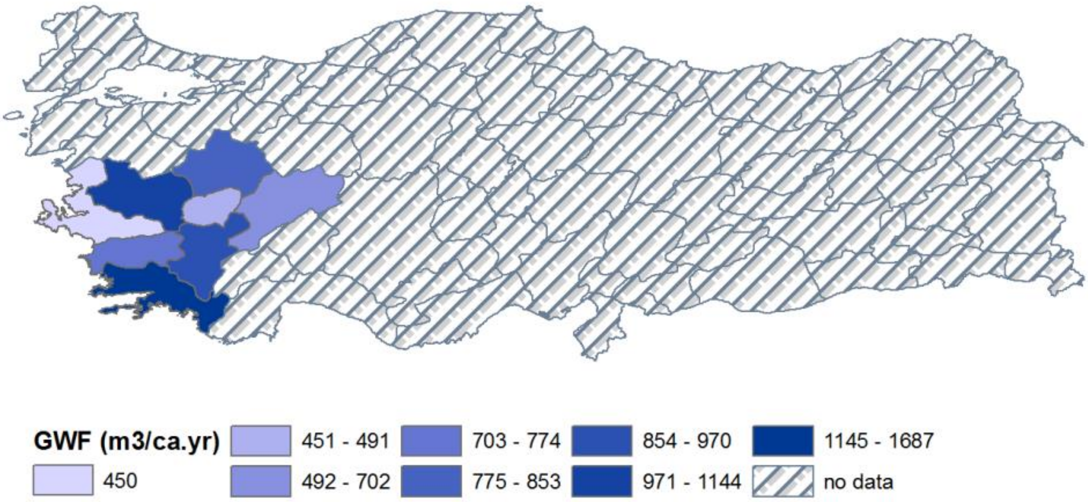


**Figure 2.** Grey water footprint of study region

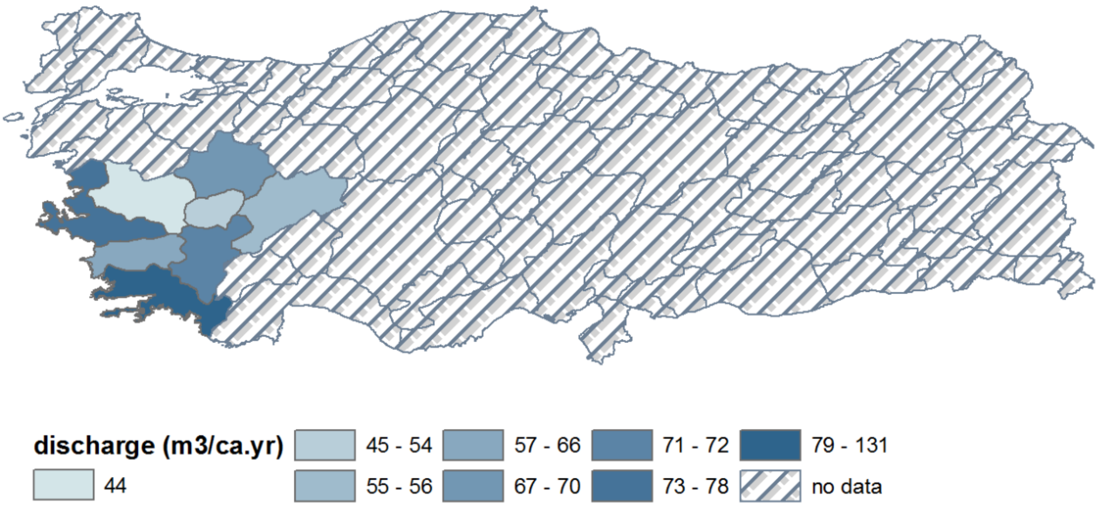


**Figure 3.** Amount of discharged municipal waste water

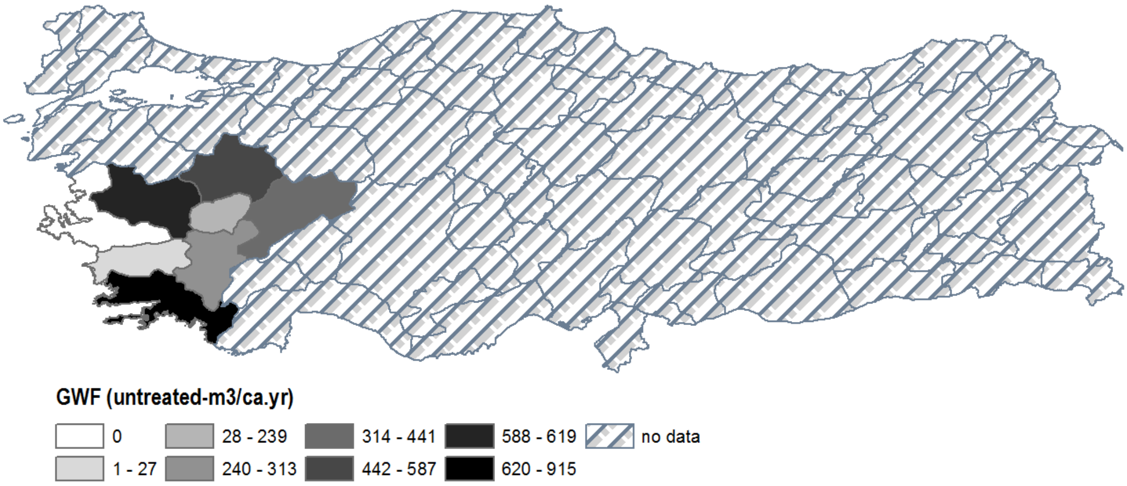


**Figure 4.** GWF from discharged wastewater (un-treated)

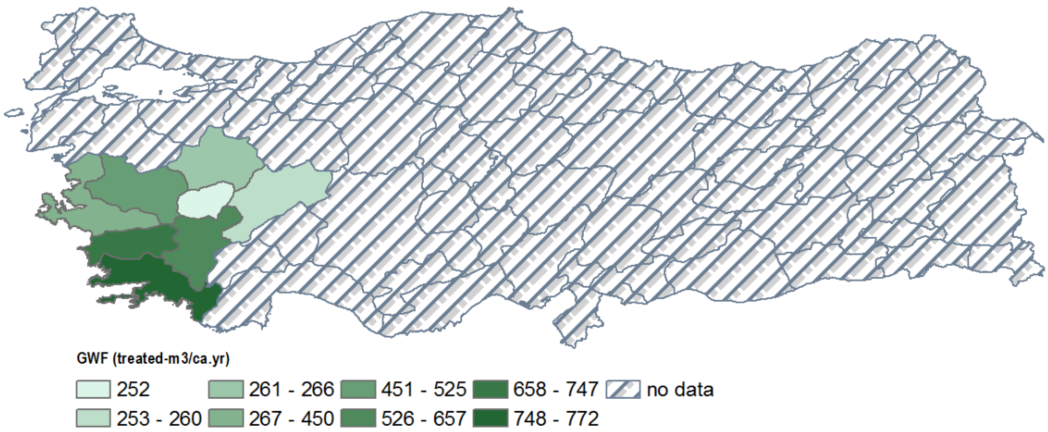


**Figure 5.** GWF from discharged wastewater (treated)

## Conclusion

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. Study results showed that GWF could be indicator to investigate effectiveness of wastewater management strategies, and determined its environmental effects.

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