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Grey water footprint of a dairy industry wastewater treatment plant: a comparative study

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Abstract

Available fresh water demand of a growing population is a fundamental concern of water resource sustainability. Dairy industry wastewater treatment plants have been considered a major polluter due to the high organic content and large wastewater discharges. Grey water footprint (GWF) was developed by the Water Footprint Network (WFN) as a measure of the water pollution loading. In this study, four treatment scenarios including no treatment process (Scenario-1), primary treatment using Dissolved Air Flotation (DAF) (Scenario-2), secondary treatment using DAF and a Upflow Sludge Bed (UASB) reactor (Scenario-3), and a DAF and UASB with a reuse application applying reverse osmosis (RO) (Scenario-4) have been studied for a full-scale dairy industry wastewater treatment plant. For these four scenarios, GWF assessment was undertaken using the WFN method by taking into consideration three pollutant parameters, chemical oxygen demand (COD), fats, oil and grease (FOG) and total suspended solids (TSS). The results show that the GWF of Scenario-4 for COD was lowest with the value of $-5{,}609$ m^3/d and Scenario-1 has the highest GWF for TSS with the value of 41,026 m^3/d. According to the assessment results, reuse applications decrease the GWF values.

Key words: climate change, dairy industry wastewater, grey water footprint, reuses

INTRODUCTION

Recently the concern regarding the environmental sustainability of water supplies, specifically the use of fresh water resources, has significantly increased due to a growing population that has a sustained water demand and this global issue has led to water scarcity (Morera *et al.* 2016). Wastewater treatment plants (WWTPs) play a crucial role within the water cycle in protecting receiving water resources from untreated discharges (Morera *et al.* 2016). But at the same time, WWTPs deplete available fresh water resources and pollute them with their discharges. Industrial wastewater plants treating highly organic wastewater are located at the top of the list due to their discharged polluting fresh water. Dairy industries discharge significant quantities of wastewater with relatively high organic matter concentrations (Amini *et al.* 2013).

Raw milk processing in Turkey has increased in recent decades and total raw milk processing in 2015 amounted to 18.5 million tons (Kırdar & Karaca 2017). As large volumes of water are required to generate dairy products, the dairy industry has been regarded as one of the main consumers of available fresh water resources and one of the main water polluters due to generating highly organic effluent (Pereira *et al.* 2018). To determine the water pollution loading of such plants, the Water Footprint Network (WFN) developed an accounting model called as the grey water footprint (GWF) (WFN 2014).

In this study, a full-scale dairy wastewater treatment plant (WWTP) in Turkey has been studied in order to determine GWF by using WFN methodology for three pollutant parameters. Four treatment

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scenarios have been compared: no treatment process (Scenario-1), a Dissolved Air Flotation (DAF) process (Scenario-2), a DAF tank and a UASB reactor (Scenario-3), a DAF tank, a UASB reactor and a reverse osmosis (RO) process (Scenario-4).

The main aim of this study was to determine the GWF of this dairy industry WWTP and to demonstrate the importance of wastewater treatment and reuse applications for reducing GWF.

METHODS

Description of the dairy industry

The GWF was evaluated for a full-scale dairy WWTP in Turkey treating 2,500 m^3/d of wastewater and discharging into the central sewage system of a centralized WWTP. The dairy industry is located in an organized industrial zone in Turkey. The main dairy products being processed are cheese, drinking milk, fruit juice, cream, milk powder, mayonnaise, yoghurt, ayran and butter. In this study, an anaerobic WWTP connected to the dairy plant with a processing capacity of 550 tons/day of raw cow milk was chosen as the reference plant. Dairy wastewater contains cooling water, sanitary wastewater and process wastewater. The major wastewater generating points of the industry are the clarification/standardization, pasteurization and homogenization processes. The wastewater is characterized in Table 1. The wastewater analysis results were obtained using Standard Methods and European Protection Agency (EPA) method (APHA 1999; EPA 2010).

Table 1 | Influent wastewater characterization of the dairy company studied

Parameter	Value
COD (mg/L)	19,550
TSS (mg/L)	4,980
FOG (mg/L)	395
pH	6.7
Flow rate (m^3/d)	2,500

Figure 1 illustrates the existing wastewater treatment process flow scheme at the plant. The major treatment units in the WWTP are an anaerobic reactor and a DAF tank. The UASB reactor is used to remove organic and suspended materials from the wastewater. In the DAF process, fats, oil, grease and particulate organic materials are removed. After this a RO process is used as a water reuse method. A portion of the reused wastewater is used as boiler feed water. The effluent is discharged to the sewage system of the Organized Industrial Zone Central Wastewater Treatment Plant. After the mixed industrial wastewater is treated at the central WWTP, the effluent is discharged to a river near the Organized Industrial Zone.

Grey water footprint accounting

GWF is described as the volume of fresh water required to dilute the pollutant loadings to meet the current water quality standards (Liu *et al.* 2012; Morera *et al.* 2016). The GWF is an indicator of water pollution loading. The recommended accounting tool for the GWF assessment in the WFA manual (Hoekstra *et al.* 2011) has been customized to the specific existence of WWTPs by Morera *et al.* (2016). To calculate GWF, an easy tool based on a mass balance was used as shown in Equation (1).

$$\mathrm{GWF} = \frac{Q_e(Ce(x) - Cmax(x))}{Cmax(x) - Cnat(x)} \tag{1}$$

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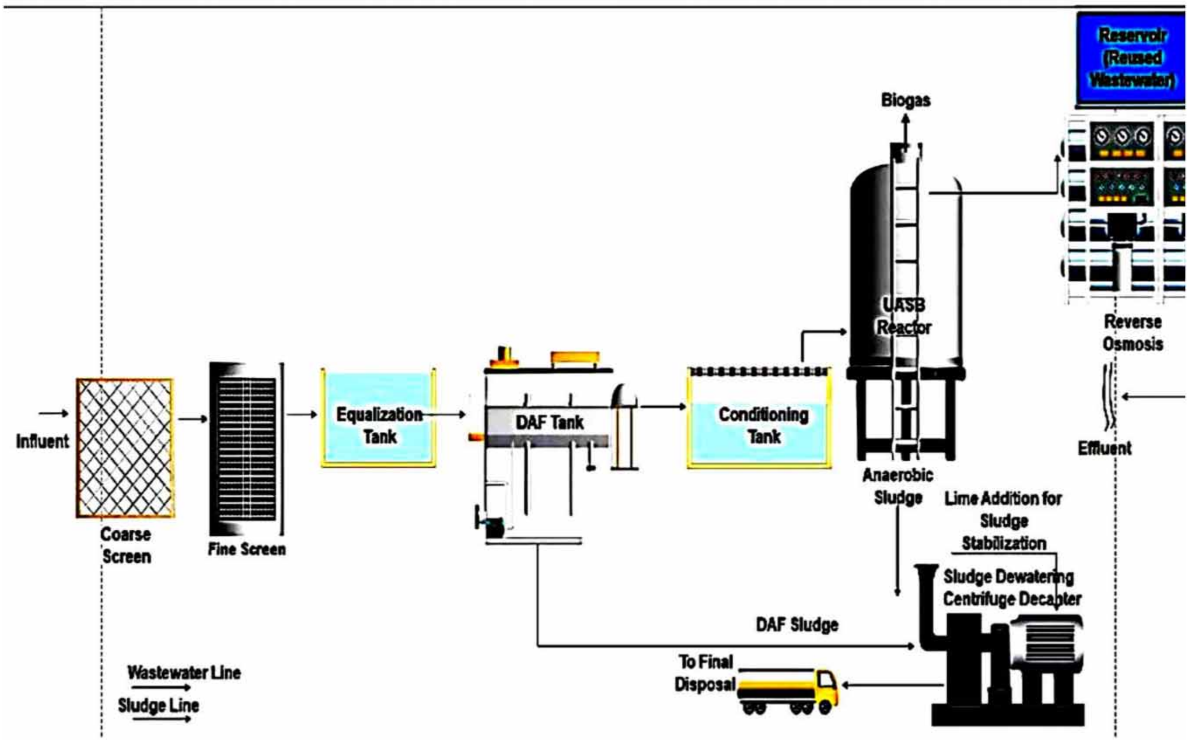

Figure 1 | Current wastewater treatment process flow diagram.

In Equation (1), Qe is the effluent flow rate (volume/time), Ce(x) is the concentration of a pollutant x in the WWTP effluent (mass/volume), Cmax(x) is the maximum concentration of pollutant x allowed in the sewage system by the legislation, and Cnat(x) is the natural concentration of pollutant x in the sewage system. Ce(x) values have been analyzed from WWTP effluent. Cnat(x) values have been obtained from the wastewater analyses of the central sewage system. Cmax(x) values have been taken from Turkish local legislation (Official Gazette 2004). Wastewater COD and TSS analysis were carried out with Standard Methods (APHA 1999). Fats, oil and grease (FOG) analysis was performed with HEM (Hexane Extractable Material) test and EPA 1664 method (EPA 2010). Table 2 presents the data set of GWF.

Table 2 | Data set of GWF

Process	Flow Rate (m^3/d)	Influent (mg/L)			Ce (mg/L)			COD (mg/L)		FOG (mg/L)		TSS (mg/L)	
		COD	FOG	TSS	COD	FOG	TSS	Cnat	Cmax	Cnat	Cmax	Cnat	Cmax
No treatment	2,500	19,550	395	4,980	19,550	395	4,980	2,251	4,000	122	250	227	500
DAF tank	2,500	19,550	395	4,980	7,821	10	1,494	2,251	4,000	122	250	227	500
UASB reactor	2,500	7,821	10	1,494	2,564	7	225	2,251	4,000	122	250	227	500
RO	2,500	2,564	7	225	76	2.5	6	2,251	4,000	122	250	227	500

Scenario-1

Scenario-1 assumes that no treatment process is implemented at the WWTP. Only coarse screening is present. Figure 2 shows Scenario-1. The main reason for choosing this scenario to underline the importance of wastewater treatment.

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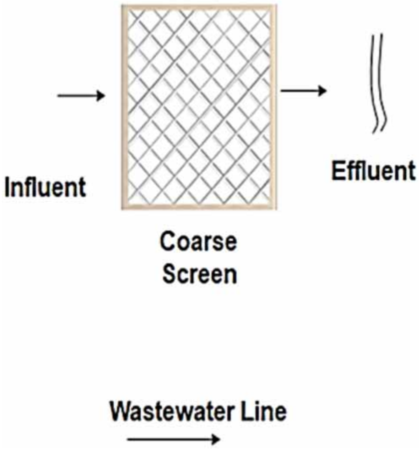

Figure 2 | Scenario-1 configuration.

Scenario-2

DAF has been used in recent decades for wastewater treatment and is often used to treat wastewater from the dairy industry with very high FOG removal efficiencies (Chung *et al.* 2000; Edzwald 2010; Falletti *et al.* 2014; Pereira *et al.* 2018). The DAF process is used before the secondary treatment step, which is normally anaerobic treatment (Castillo *et al.* 2017). Scenario-2 uses a DAF tank as the preliminary treatment for treating the dairy wastewater and is shown in Figure 3.

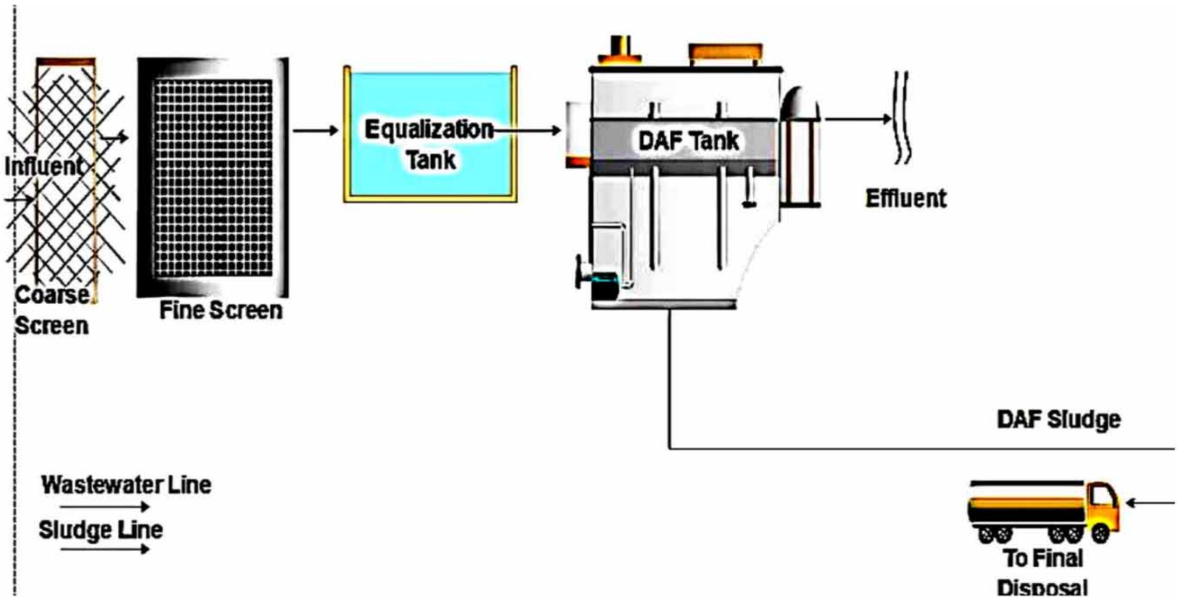

Figure 3 | Scenario-2 configuration.

Scenario-3

Anaerobic treatment is one of the oldest wastewater treatment techniques found all over the world (Speece 1996). Anaerobic biotechnology is frequently used to treat many industrial wastewaters (Speece 1996). It is suitable for very highly loaded organic wastewaters such as that found in the dairy industry. Anaerobic technology includes different reactor configurations such as UASB, expanded granular sludge bed (EGSB), and anaerobic filters (AFs) (Metcalf & Eddy 2014). Among

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them, the UASB reactor is widely preferred for dairy wastewater treatment (Gavala *et al.* 1999; Ozturk *et al.* 2003). Scenario-3 is composed of dairy wastewater treatment using a DAF process followed by a UASB reactor as shown in Figure 4.

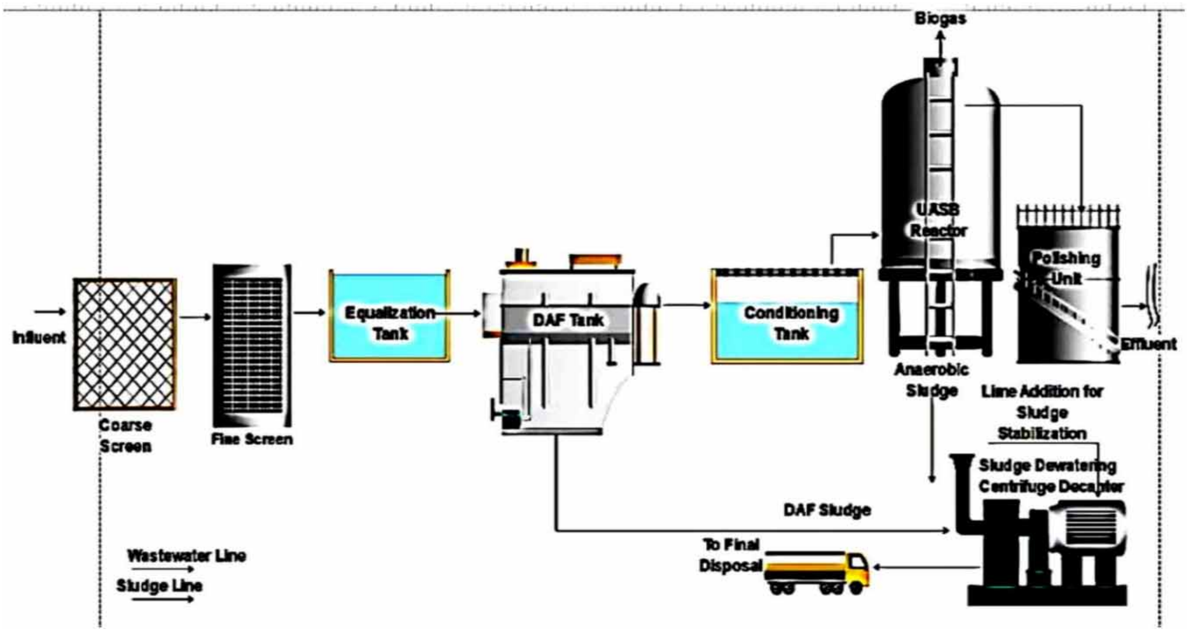

Figure 4 | Scenario-3 configuration.

Scenario-4

Membrane technology is an alternative and advanced treatment method for dairy wastewater treatment. Wastewater reuse application has an important place in climate change impacts mitigation strategies (Metcalf & Eddy 2014). Membrane technologies have been applied for wastewater reuse and reclamation. The RO process is widely used for dairy wastewater reuse (Bickers & Bhamidimarri 1998; Vourch *et al.* 2008). Scenario-4 is a DAF and USAB followed by a RO process as shown in Figure 5.

RESULTS AND DISCUSSION

GWF assessment of dairy industry WWTP

Figure 6 and Table 3 show the GWF assessment of Scenario (1–4). The highest GWF (41,026 m^3/d) corresponds to the TSS parameter in the no treatment scenario. This result underlines the significance of wastewater treatment availability. If the wastewater is discharged without treatment, the highest water pollution loading is observed. As well, the $GWF_{,COD}$ and $GWF_{,FOG}$ were relatively higher than the other GWF values of treatment Scenarios (2-4). The second highest GWF values correspond to Scenario-2 that uses a DAF process. Total GWF values of Scenario-1, Scenario-2, Scenario-3 and Scenario-4 are 66,085, 9,877, −9,317 and −14,967 m^3/d, respectively. It can be noted the negative values imply a dilution of Cnat.

In the results of the assessment, the lowest GWF corresponds to the COD parameter and Scenario-4 where RO is used as the reuse application with the value of −5,609 m^3/d. This is due to the high COD, TSS and FOG removal efficiencies of the RO process that led to the lowest Ce

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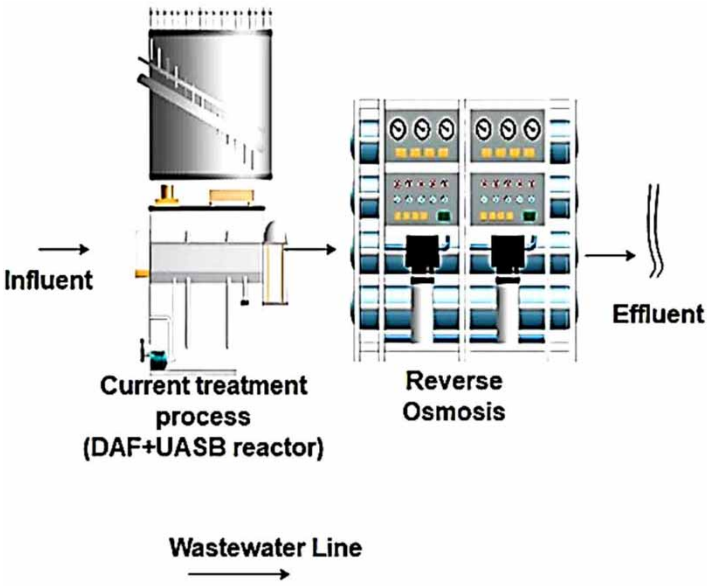

Figure 5 | Scenario-4 configuration.

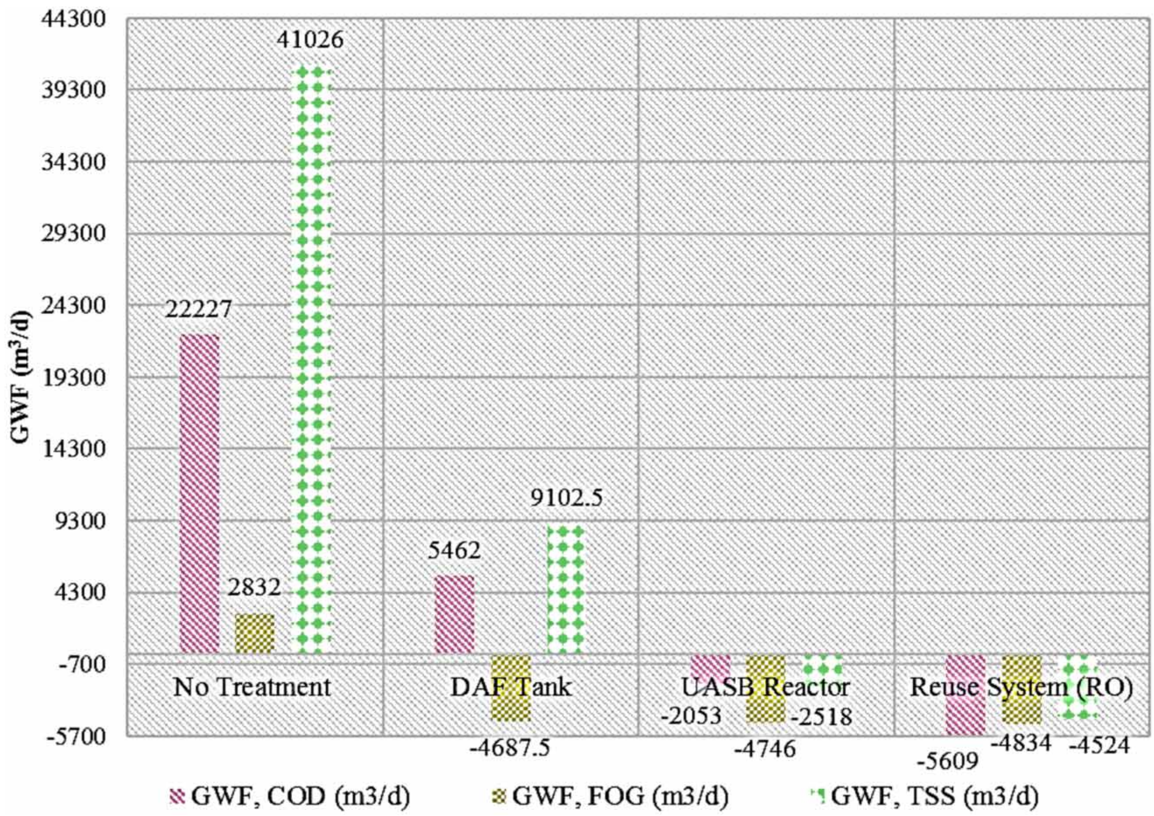

Figure 6 | GWF assessment.

value. As Ce concentrations decrease with improved treatment, GWF decreases as well. Also, for all pollutant parameters, Scenario-4 has the lowest GWF values. Morera *et al.* (2016) obtained results similar to this study. They reported the highest GWF for no-treatment scenario, the second highest GWF for the existing treatment scenario and the lowest GWF corresponded to the scenario where

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Table 3 | GWF assessment of dairy industry WWTP

Process	GWF, $_{COD}$ (m^3/d)	GWF, $_{FOG}$ (m^3/d)	GWF, $_{TSS}$ (m^3/d)	GWF, $_{total}$ (m^3/d)
No treatment	22,227	2,832	41,026	66,085
DAF tank	5,462	−4,687.5	9,102.5	9,877
UASB reactor	−2,053	−4,746	−2,518	−9,317
RO	−5,609	−4,834	−4,524	−14,967

the wastewater treatment included chemical phosphorus removal. If Ce values decrease with treatment, GWF also decreases.

The results illustrate that pollutant removal efficiency is very important for the GWF. As the pollution removal efficiency increases, the GWF decreases.

The impact of reuse application on GWF assessment

It is possible to mitigate GWF using a reuse process. It was observed that there is an important reduction (38%) of the water footprint when RO is added to the existing treatment process. When RO is implemented, total GWF value is −14,967 m^3/d. If RO is not implemented, the total GWF value is −9,317 m^3/d for the existing treatment process (DAF process and UASB reactor). Figure 7 presents the comparison of the total GWF values of the processes.

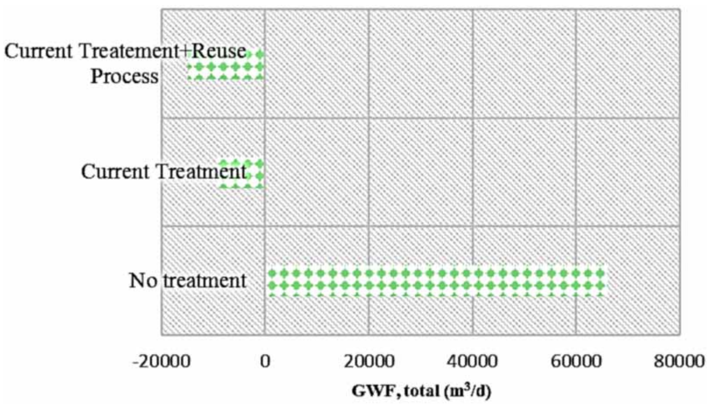

Figure 7 | Total GWF comparison of scenarios.

CONCLUSIONS

This study demonstrates that it is possible to use the GWF methodology to determine the water pollution loading of industrial WWTPs.

It is possible to decrease the GWF using reuse processes in a dairy WWTP. A reduction up to 38% has been observed by combining the existing treatment method with a RO process. For minimizing GWF, reuse applications can be carried out.

The lowest GWF corresponds to the Scenario-4 that uses the existing treatment process and RO process for three pollutant parameters. This is due to the high pollutant removal efficiencies of the RO process that yields the lowest Ce concentration values. In the results of this assessment, the lowest GWF corresponds to the COD parameter and the highest GWF correspond to the TSS parameter. So, TSS leads to the highest water pollution loading for a dairy WWTP in Turkey.

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REFERENCES

Amini, M., Younesi, H., Zinatizadeh-Lorestani, A. A. & Najafpour, G. 2013 Determination of optimum conditions for dairy wastewater treatment in UAASB reactor for removal of nutrients. *Bioresource Technology* **145**, 71–79.

APHA/AWWA/WEF 1998 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Bickers, P. O. & Bhamidimarri, R. 1998 Aerobic treatment of reverse osmosis permeate in the dairy industry for reuse. *Water Science and Technology* **38**(4–5), 61–67.

Castillo, A., Vall, P., Garrido-Baserba, M., Comas, J. & Poch, M. 2017 Selection of industrial (food, drink and milk sector) wastewater treatment technologies: a multi-criteria assessment. *Journal of Cleaner Production* **143**, 180–190.

Chung, Y., Choi, Y. C., Choi, Y. H. & Kang, H. S. 2000 A demonstration scaling-up of the dissolved air flotation. *Water Research* **34**, 817–824.

Edzwald, J. K. 2010 Dissolved air flotation and me. *Water Research* **44**, 2077–2106.

EPA 2010 United States Office of Water. Environmental Protection Agency (4303), February 2010. Method 1664, Revision B: n-Hexane, USA.

Falletti, L., Conte, L., Zaggia, A., Battistini, T. & Garosi, D. 2014 Food industry wastewater treatment plant based on flotation and MBBR. *Modern Environment Science and Engineering* **1**, 562–566.

Gavala, H. N., Kopsinis, H., Skiadas, I. V., Stamatelatou, K. & Lyberatos, G. 1999 Treatment of dairy wastewater using an upflow anaerobic sludge blanket reactor. *Journal of Agricultural Engineering Research* **73**(1), 59–63.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. & Mekonnen, M. M. 2011 *The Water Footprint Assessment Manual*. Earthscan, London-Washington, DC.

Kırdar, S. S. & Karaca, O. B. 2017 An overview of the Turkish dairy sector. *Indian Journal of Dairy Science* **70**(3), 249–255.

Liu, C., Kroeze, C., Hoekstra, A. Y. & Gerbens-Leenes, W. 2012 Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. *Ecological Indicators* **18**, 42–49.

Metcalf & Eddy. 2014 *Wastewater Engineering: Treatment and Resource Recovery*, 5th ed. McGraw-Hill, Boston, USA.

Morera, S., Corominas, L., Poch, M., Aldaya, M. M. & Comas, J. 2016 Water footprint assessment in wastewater treatment plants. *Journal of Cleaner Production* **112**, 4741–4748.

Ozturk, I., Eroglu, V., Ubay, G. & Demir, I. 2003 Hybrid upflow anaerobic sludge blanket reactor (HUASBR) treatment of dairy effluents. *Water Science and Technology* **28**, 77–85.

Pereira, M. S., Borges, A. C., Heleno, F. F., Squillace, L. F. A. & Faroni, L. R. D. 2018 Treatment of synthetic milk industry wastewater using batch dissolved air flotation. *Journal of Cleaner Production* **189**, 729–737.

Speece, R. E. 1996 *Anaerobic Biotechnology for Industrial Wastewaters*. Archae Press, USA.

T.C. Official Gazette 2004 *Water Polllution Control Procedure*. Ankara, Turkey. http://www.mevzuat.gov.tr/Metin.Aspx?MevzuatKod=7.5.7221&sourceXmlSearch=&MevzuatIliski=0 (accessed 20 May 2018).

Vourch, M., Balannec, B., Chaufer, B. & Dorange, G. 2008 Treatment of dairy industry wastewater by reverse osmosis for water reuse. *Desalination* **219**(1–3), 190–202.

Water Footprint Network, WFN 2014 http://waterfootprint.org/. (accessed 20 May 2018).