JOURNAL OF SCIENCE
SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University |
http://www.saujs.sakarya.edu.tr/

Title: Seasonal Water Footprint Assessment For A Paint Industry Wastewater Treatment Plant

Authors: Pelin Yapıcıoğlu
Recieved: 2018-03-30 00:00:00
Revised: 2018-07-08 00:00:00
Accepted: 2018-10-16 00:00:00
Article Type: Research Article
Volume: 23
Issue: 2
Month: April
Year: 2019
Pages: 175-183

How to cite
Pelin Yapıcıoğlu; (2019), Seasonal Water Footprint Assessment For A Paint Industry Wastewater Treatment Plant. Sakarya University Journal of Science, 23(2), 175-183, DOI: 10.16984/saufenbilder.411137
Access link
http://www.saujs.sakarya.edu.tr/issue/39539/411137

Sakarya University Journal of Science 23(2), 175-183, 2019

Seasonal water footprint assessment for a paint industry wastewater treatment plant

Pelin Yapıcıoğlu[*1]

Abstract

Paint manufacturing industries have many unfavorable environmental impacts such as freshwater consumption. Especially, paint industry wastewater treatment plants consume huge water volumes. Water footprint is described as the total volume of water required for a concept. The main aim of the study is to determine the seasonal variation of water footprint for a full-scale paint industry wastewater treatment plant which locates in Turkey. Grey water footprint was evaluated by Water Footprint Network methodology. Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Oil and Grease (O&G) are the pollutant parameters to detect it. Water consumption of the plant contains sludge treatment, process water usage and other residential activities are defined as the component of blue water footprint. According to the results, maximum grey water footprint was measured in May as the value of 2455.840352 $m^3.month^{-1}$. The least total grey water footprint is related to August as 536.7118464 $m^3.month^{-1}$. Total blue water footprint is 4866.9 $m^3.year^{-1}$ and the peak value is 421.7 $m^3.month^{-1}$ in March. According to the study, the grey water footprint is higher than blue footprint. The results reveal that for decreasing water footprint, COD removal efficiency should be increased and wastewater reuse alternatives should be implemented.

Keywords: paint industry wastewater, water footprint, climate change

1. INTRODUCTION

The paint industry is defined as huge water consumer and owner of huge discharge volumes of colorful wastewater with supernal chemical oxygen demand (COD) and nonorganic loading, establishing it one of the major supplies of serious contamination around the world [1,2]. In this context, it has a climate change effect because of its treatment process. Industrial wastewater treatment plants consume a large amount of freshwater due to their processes, chemical usage, treatment requires, energy consumption and residential activities [3].

Paint industry wastewater treatment plants have a significant role on freshwater consumption. In the result of climate change, natural water resources have been depleted recently. Water scarcity is the deficiency of adequate available freshwater supplies to fulfil water requirements in a region. Turkey has been considered as the one of the main countries that will have been enforced by global warming. Water supplies management has the importance for the countries that have water scarcity problem such as Turkey. In a survey conducted by the World Resources Institute (WRI), Turkey is among the countries that would suffer serious water scarcity by 2040 [4]. The water footprint is a depletion-based index of water utilization that reviews both direct and indirect water utilization of a user or producer [3]. Water footprint of paint industry wastewater treatment plants should be determined and calculated for water resources management and consumption controlling. In this study, grey water footprint was evaluated with concerted Water Footprint Network (WFN) methodology by considering three types of pollutant indicators as COD, TSS and O&G

* Harran University, Faculty of Engineering, Environmental Engineering Department, Şanlıurfa - pyapicioglu@harran.edu.tr

for a paint industry wastewater treatment plant. In addition, blue water footprint was assessed from total water consumption of the treatment plant due to sludge treatment, process water usage and residential activities of employees. It is essential to minimize the water footprint while the water resources have been consuming.

1.1. Water Footprint (WF) Definition

The notion of water footprint was firstly identified in 2002 by Arjen Hoekstra [5]. The notion of water footprint was developed by Twente University and Water Footprint Network (WFN). Water footprint means the required freshwater for generation of a product or an activity. Water Footprint is measured by consuming water in unit time and/or the extent related to polluted water [6]. This concept related to a product is a poly-dimensional index. The water footprint (WF) is regarded as comparative index that measures the sum of freshwater mass that is utilized [7].

Total water footprint comprises of three components. One of them is consumption of surface water and groundwater, the other one is depletion of rainwater stocked in the soil named as soil moisture, and the last one is freshwater mass that is needed to assimilate the pollutants loading [8]. The green water footprint is the total mass of rainwater depleted during the crop manufacturing process, particularly it contains depleted rainwater volume for crops and plants growth and the evapotranspiration from agricultural and forestry products and plants [8]. Green water footprint is especially concerned for agricultural crops which require rainwater to grow. Industrial wastewater treatment plants are out of this scope because there is no crop production in these facilities. The grey water footprint is an index of water contamination. Therefore, the WF does not only quantify the amount of water supplies utilized, but it also calculates contamination [9]. Blue water is defined as consumed freshwater, and the blue water footprint is the quantity of the water originated from these natural water supplies such as surface water and groundwater.

1.2. Water Footprint of Wastewater Treatment Plants

Wastewater treatment plants (WWTPs) have been considered as one of the most significant water consumers in Turkey [10]. WWTPs act a crucial part inside the water cycle [3]. Water footprint of wastewater treatment plants should be calculated to know the environmental impacts. Water Footprint assessment gets easier to implement life cycle assessment. In addition, water supplies have been consumed and it causes climate change and it can be quantified by the water footprint term.

2. MATERIAL-METHOD

2.1. Definition of the Methodology

There are two approaches to estimate water footprint in the literature. The bottom-up approach [5,11,12,13,14,15] and the top-down approach [16,17,18,19,20,21]. To assess the water footprint of products and services, Water Footprint Network (WFN) improved a methodology to fulfill water footprint assessment (WFA) [8].

Three pollutant parameters that include COD, TSS and O&G are the indicators to calculate grey water footprint between January and December. In this study, grey water footprint was calculated by concerted Water Footprint Network (WFN). Modified equation model has been used and dataset has been formed includes 12 months analysis and the seasonal variation of the water footprint. The equation (1) is below for calculating grey water footprint of the wastewater treatment plant. It is derived from WFN methodology by considering Turkish Environmental Law [22].

$$WF_{grey}=Q_e\,(C_{max}-C_e)\,/\,(C_{max}-C_{nature}) \quad (1)$$

In Eq. (1), Q_e is the effluent flow rate (volume/time), C_e is the concentration of a contaminant in the WWTP effluent (mass/volume), C_{max} is the maximum concentration of a contaminant allowed in the receiver water media, and C_{nature} is the natural concentration of a contaminant in the receiver water media.

The blue water footprint of the wastewater treatment plant is the sum of the water consumption monthly. It has been detected from the water counters in the plant. Blue water footprint was calculated using following equation (2).

$$WF_{blue,\,total}=WF_{blueST}+WF_{blueP}+WF_{blueRA} \quad (2)$$

In Eq. (2) WF_{blueST} describes water consumption for sludge treatment, WF_{blueP} is process water consumption and WF_{blueRA} is water consumption of other residential activities.

The water footprint of the plant is the sum of the grey water footprint and blue water footprint. It was calculated using following equation (3).

$$WF_{Total} = WF_{blue} + WF_{grey} \quad (3)$$

2.2. Description of the Case Study

The paint industry wastewater treatment plant is located in an organized industrial zone in Turkey. Water scarcity is the most significant problem for this WWTP because Turkey is under the risk. Wastewater treatment process flow diagram is given in Figure1. Chemical treatment method is implemented as coagulation and flocculation process and activated carbon adsorption to remove color, organic and suspended materials from wastewater. In DAF (dissolved air flotation) tank, oil and grease and other organic material removal have been obtained. Disinfection is fulfilled for pathogens and microorganism removal from effluent. Activated carbon adsorption is implemented for color removal from wastewater. The wastewater is discharged to the Organized Industrial Zone Central Wastewater Treatment Plant; the receiver water body is the river nearby to Organized Industrial Zone Central Wastewater Treatment Plant.

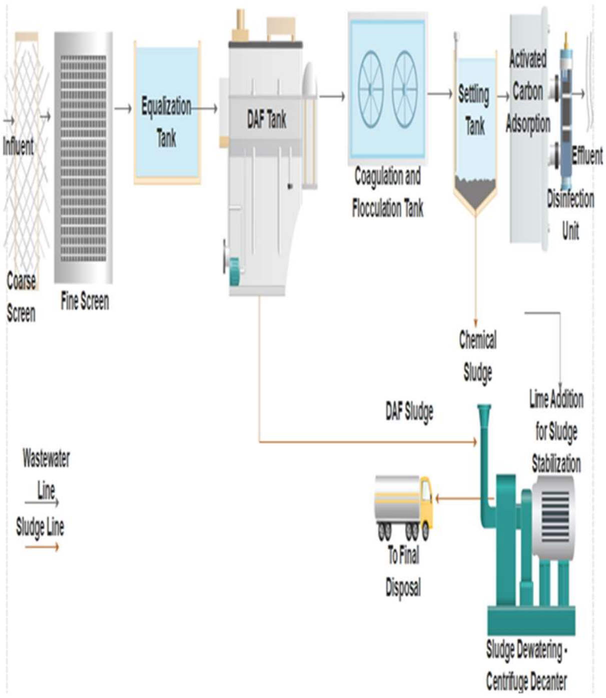

Figure 1. Wastewater Treatment Process Flow Diagram

The wastewater characterization and the limit concentration and natural concentration of pollutants are given in Table 1. Wastewater and receiver water body COD and TSS measurements were fulfilled with Standard Methods [23] between January and December, monthly. Oil and grease (O&G) analysis was realized with HEM (Hexane Extractable Material) test and EPA 1664 method [24]. The flow rate has been measured with flux meter for 12 months.

The dataset for calculating WF_{blue} is given in Table 2. The water consumption counters were emplaced to each measurement areas for assessment of WF_{blue}.

Table 1. Dataset of WF_{grey}

	Influent				Effluent			COD (mg/L)		O&G (mg/L)		TSS (mg/L)	
Months	Flow Rate ($m^3 \cdot month^{-1}$)	COD (mg/L)	O&G (mg/L)	TSS (mg/L)	COD (mg/L)	O&G (mg/L)	TSS (mg/L)	C_{nature}	C_{max}	C_{nature}	C_{max}	C_{nature}	C_{max}
January	3250	5970	421	1463	305	18.75	197.5	108	400	6.3	20	101.5	200
February	3450	5325	418	1250	312	19	198	112	400	6.5	20	105	200
March	2200	4878	420	1158	287	18	199	125	400	6.8	20	104.75	200
April	2741	4910	415	1225	319	18.5	170	119	400	6.9	20	105.9	200
May	2980	5875	398	1259	289	17.8	175	107	400	7.1	20	109	200
June	2225	5900	410	1141	295	19.8	180.5	106	400	7.3	20	102.5	200
July	2890	5150	413	1427	325	19.7	182	115	400	7.8	20	102	200
August	1990	5225	395	1415	367	19.5	189	121	400	6.85	20	103	200
September	2245	5297	389	1255	379	18.9	178	122	400	6.75	20	108	200
October	3980	5110	405	1312	371	17.96	196.5	169	400	7.35	20	106.75	200
November	3580	4950	402	1340	389	17.45	198.5	171	400	7.44	20	107	200
December	3890	4990	397	1378	388	17	198	141	400	8.9	20	110	200

Table 2. Dataset of WF_{blue}

Months	Sludge treatment, $WF_{blue\ ST}$ ($m^3.month^{-1}$)	Process Water Usage, $WF_{blue\ P}$ ($m^3.month^{-1}$)	Other Residential Activities, $WF_{blue\ RA}$ ($m^3.month^{-1}$)
January	189.7	158	68.7
February	234.4	102	62
March	222.5	170	29.2
April	259.5	102	14.3
May	178	145	80.8
June	199.8	136	85.6
July	194.6	153	67.2
August	179.4	143	96
September	187	144	83.4
October	190	157	7.4
November	193.8	161	57.6
December	197	155	63
Total	2425.7	1726	715.2

3. RESULTS AND DISCUSSION

In calculating total water footprint, measurement and analysis values have been determined. The results of the assessment that were ensured have been shown in Table 3 and the seasonal evaluation is given in Figure 2.

Table 3. Seasonal Variation of the Total Water Footprint (WF_{grey}, WF_{blue} and WF_{total})

Months	$WF_{grey,COD}$ ($m^3.month^{-1}$)	$WF_{grey,O\&G}$ ($m^3.month^{-1}$)	$WF_{grey,TSS}$ ($m^3.month^{-1}$)	$WF_{grey,total}$ ($m^3.month^{-1}$)	WF_{blue} ($m^3.month^{-1}$)	WF_{total} ($m^3.month^{-1}$)
January	1057.363014	296.5328467	82.48730964	1436.38317	416.4	1852.783
February	1054.166667	255.5555556	72.63157895	1382.353801	398.4	1780.754
March	904	333.3333333	23.09711286	1260.430446	421.7	1682.13
April	790.1103203	313.8549618	873.8575983	1977.82288	375.8	2353.623
May	1128.94198	508.2170543	818.6813187	2455.840352	403.8	2859.64
June	794.6428571	35.03937008	445	1274.682227	421.4	1696.082
July	760.5263158	71.06557377	530.8163265	1362.408216	414.8	1777.208
August	235.3763441	75.66539924	225.6701031	536.7118464	418.4	955.1118
September	169.5863309	186,3773585	536.8478261	892.8115155	414.4	1307.212
October	499.6536797	641.8339921	149.383378	1290.87105	354.4	1645.271
November	171.9650655	726.8312102	57.74193548	956.5382112	412.4	1368.938
December	180.2316602	1051.351351	86.44444444	1318.027456	415	1733.027
Total	7746.564234	4495.658007	3902.658932	16144.88117	4866.9	21011.78

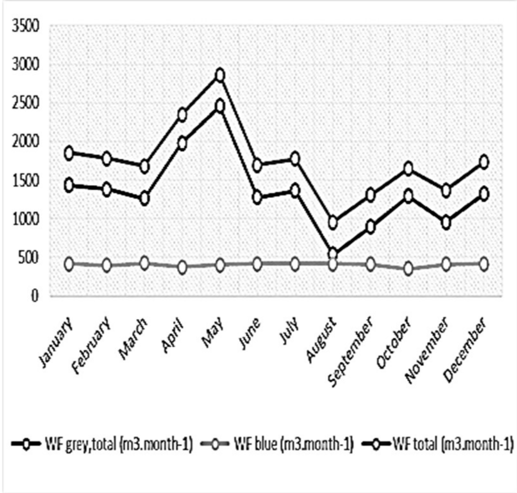

Figure 2. Seasonal Evaluation of Water Footprint

According to evaluation results, the maximum total water footprint is 2859.640352 $m^3.month^{-1}$ related to May in the spring. August has the minimum total water footprint value as 955.1118464 $m^3.month^{-1}$. If we consider the seasonal variation, in the spring total water footprint is 6895.393679 $m^3.month^{-1}$ as the peak value. The autumn has the minimum total water footprint as 4321.420776 $m^3.mont^{-1}$. The winter and the summer have the water footprint values as 5366.564427 and 4428.40229 $m^3.month^{-1}$, respectively. Total water footprint value is 21011.78117 $m^3.month^{-1}$. Total water footprint is closely related to total grey water footprint. $WF_{greyCOD}$, $WF_{greyTSS}$ and $WF_{greyO\&G}$ have been calculated and compared seasonally and Figure 3 demonstrates the seasonal grey water footprint evaluations.

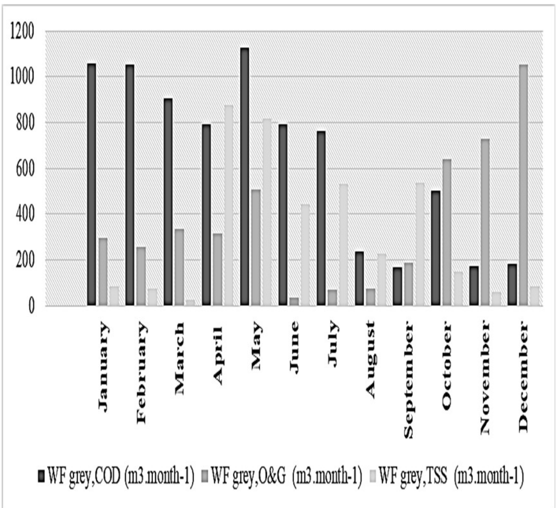

Figure 3. Seasonal Variation of Grey Water Footprint ($WF_{greyCOD}$)

May has the maximum WF $_{grey,total}$ value as 2455.840352 $m^3.month^{-1}$ and August has the least value as 536.7118464 $m^3.month^{-1}$. It is in relationship with the discharge point natural pollutant concentration. If the plant discharges the pollutants are in huge amounts and very higher than the C_{nature}, grey water footprint increases. The impact of the pollutant in the WWTP is closely related to the receiver water body characterization. In the spring, it has been observed the maximum total grey water footprint as 5694.093679 $m^3.month^{-1}$. Autumn has the minimum grey water footprint as 3140.220776 $m^3.month^{-1}$. The total grey water footprint values related to three pollutant parameters that contain COD, TSS and O&G are 7746.564234, 3902.658932 and 4495.658007 $m^3.year^{-1}$, respectively. COD causes the maximum grey water footprint and the minimum total grey water footprint formed due to TSS. If we increase the COD removal efficiency, the minimum grey water footprint could be formed. The natural pollution (c_{nature}) in the receiver water media acts an important role to assess the grey water footprint. If the natural pollution in the discharge point is in the very low amounts, the grey water footprint is higher.

Blue water footprint evaluation is predicted on freshwater consumption of the wastewater treatment plant. Sludge treatment, process water usage and other residential activities (personal water consumption, cleaning etc.) have been discussed in this step. In Figure 4, the seasonal blue footprint variation is given.

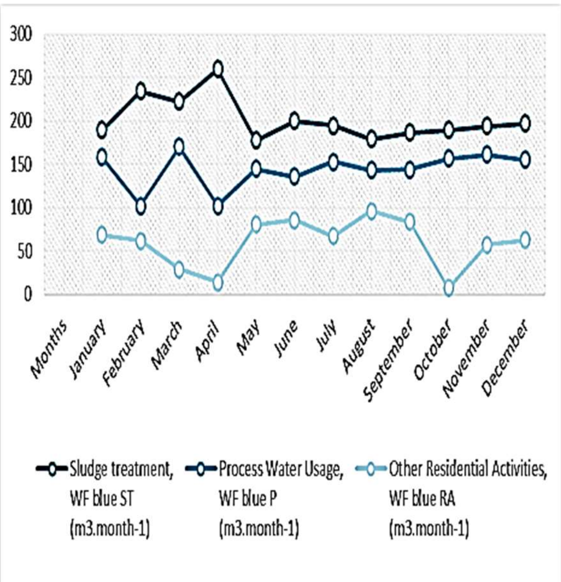

Figure 4. Seasonal Blue Footprint Variation

The results revealed that the total blue water footprint is 4866.9 $m^3.year^{-1}$ and the blue water footprint due to the sludge treatment has the maximum value as 2425.7 $m^3.year^{-1}$. Sludge handling process requires huge amounts of water. Because of this reason, its portion has the highest value in blue water footprint. Total blue water footprint of process water usage and other residential activities are 1726 and 715.2 $m^3.year-^1$, respectively. The highest total blue water footprint was observed in March as 421.7 $m^3.month^{-1}$. October has the minimum total blue water value as 354.4 $m^3.month^{-1}$. If we mention about seasonal variation of the water footprint, the summer has the peak total water footprint that is 1254.6 $m^3.month^{-1}$. Autumn has the minimum total water footprint value with 1181.2 $m^3.month^{-1}$ such as grey water footprint. The values of blue water footprint belong to winter and spring are 1229.8 and 1201.3 $m^3.month^{-1}$, respectively.

In the literature, water footprint studies for WWTPs are limited. These type studies should be developed. This case study demonstrates that it is possible to measure water footprint in WWTPs with a simple calculation term and it will be enable to assess seasonal water footprint evaluation. In similarly, Morera et al. (2016) studied the water footprint of a municipal wastewater plant. They used three scenarios: no treatment, secondary treatment and phosphorus removal. They calculated blue and grey water footprint with similar WFN method. A minimization of the water footprint by 51.5% and 72.4% was obtained implementing secondary treatment and chemical phosphorus removal. These results demonstrate that when treating wastewater, there is an important reduction in the grey water footprint in comparison with the no treatment scenario however, there is a less amount blue water footprint [3]. Morera et al. (2016) studied for the municipal La Garriga WWTP; in this study paint industry wastewater treatment plant is the pilot plant. They used three pollutant parameters for grey water footprint as TN (Total Nitrogen), TP (Total Phosphorus) and TOC (Total Organic Carbon), similarly COD, O&G and TSS have been used in this study. The results of their study were 539.317 $m^3.month^{-1}$; 3,448.115 $m^3.month^{-1}$ and 261.779 $m^3.month^{-1}$ for TN, TP and TOC. TP causes the maximum greywater footprint and TOC caused the minimum grey water footprint in their study, in this study, COD causes the maximum grey water footprint and the minimum total grey water footprint formed due to TSS. According to their study, the blue WF for the current wastewater treatment scenario was 180.180 $m^3.month^{-1}$ where the major contributors are the energy consumption, in this study for blue water footprint major component was sludge treatment. While comparing with this study, the similarity has been observed. This study also revealed that grey water footprint is higher than blue water footprint, too. It shows that this methodology could be implemented for every pollutant parameters and pollution parameters create different impacts. The similar study was undertaken by Gomez-Llanos et al. (2018) [25]. In their study, operational greywater footprint was proposed to evaluate the remediation of the effluent quality. They studied for BOD_5 (Biological Oxygen Demand in 5 days), TP and TN for two wastewater treatment plants. They observed for both plants, BOD_5 of grey water footprint was higher than the other parameters with the values of nearly $4.6x10^6$-$3x10^6$ $m^3.month^{-1}$. The minimum grey water footprint was related to TN with the values of in the range of 0.5-$1.5x10^6$ $m^3.month^{-1}$. From this point of the view, it can be said that the grey water footprint of their urban plant were much higher than this paint manufacturing industry. The other study was related to Martínez-Alcala et al. 2018 [26]. They tried to determine the pharmaceutical grey water footprint. Conventional pollutants (nitrate, phosphates and organic matter) were measured as the total nitrogen (TN), total phosphorus (TP) and BOD5, respectively for 12 pharmautical wastewater treatment plants. They observed that an increase of 118.106 $m^3.year^{-1}$ due to the pharmaceutical pollutants in the treated wastewater that is reused and the three treatment plants that discharge into the environment generate a grey water footprint of 237.106 $m^3.year^{-1}$. Grey water footprint of TP was higher than the other parameters. The smallest grey water footprint was related to TN. This study confirms that this tool can be applied for the industrial plants and various pollutant substances. The oldest study was related to Shao and Chen (2012) [27]. The water footprint of a wastewater treatment plant is estimated as $1.64x10^5$ m^3 freshwater, with intensities of $3.12x10^{-3}$ m^3 freshwater/m^3 wastewater, 1.33×10^{-2} m^3 freshwater/kg BOD_5, $1.04x10^{-2}$ m^3 freshwater/kg COD, and 3.90x101 m^3/10 000 CNY (Chinese Yuan). Acoording to the results, greywater footprint of COD was higher than the BOD_5's. In this study, similarly COD was the highest grey water footprint.

This study not only adds seasonal variation and comparison to the literature but also, differently the estimation has been done for COD, O&G and TSS parameter for an industrial wastewater treatment plant.

4. CONCLUSIONS

WWTPs are one of the significant water consumer facilities in Turkey. WF_{total} of a paint industry wastewater treatment plant in Turkey was 21011.78117 $m^3.year^{-1}$ and the maximum total footprint value that was 6895.393679 $m^3.month^{-1}$ was detected in the spring. The minimum total water footprint was monitored in the autumn in the value of 4321.420776 $m^3.month^{-1}$.

The highest value related to total water footprint is grey water footprint with the value of 2455.840352 $m^3.month^{-1}$ and it was observed in May in the spring. The least value related to the august as 536.7118464 $m^3.month^{-1}$. Among the pollutant parameters, COD caused grey water footprint had the maximum value as 7746.564234 $m^3.year^{-1}$. The results demonstrated that C_{nature} in the receiver water body plays a significant role to evaluate the grey water footprint. If the natural contamination in the receiver water body is in low amounts, the grey water footprint is higher. Blue water footprint is less than grey water footprint. Sludge treatment is 50% of blue water footprint in the wastewater treatment plant. Process water usage and other activities are 35% and 15% respectively. To decrease blue water footprint, water usage for sludge handing unit should be limited.

The results revealed that grey water footprint values have paralleled with total water footprint. Water pollutant capacity plays a major role in water footprint assessment. At the same time, the natural pollutant concentration of the water body that is discharged is very important to detect grey water footprint. For minimizing grey water footprint, higher COD removal should be applied. For decreasing the organic loading rate could be increased and hydraulic retention time in the equalization tank and chemical treatment unit can be increased. Blue water footprint can be decreased by ensuring wastewater reuse and reclamation. Reclaimed wastewater could be used for the sludge dewatering process instead of the freshwater. Before the discharge to the receiver media, the effluent could be retreated and reused as the process water with an advanced process such as membrane processes, advanced oxidation processes and electrochemical processes.

REFERENCES

[1] J. Yao, D. Wen, “Zero Discharge Process for Dyeing Wastewater Treatment,” *Journal of Water Process Engineering,* vol. 11 , pp. 98-103, 2016.

[2] P. Yapıcıoğlu, “Investigation of Environmental-friendly Technology for a Paint Industry Wastewater Plant in Turkey,” *Süleyman Demirel University Journal of Natural and Applied Sciences*, online published, 2018. Doi: 10.19113/sdufbed.22148.

[3] S. Morera, L. Corominas, M. Poch, M.M. Aldaya and J. Comas, “Water footprint assessment in wastewater treatment plants,” *Journal of Cleaner Production,*vol. 112, pp. 4741–4748, 2016.

[4] World Resources Institute, WRI, 2015. Available: http://www.wri.org/. [Accessed 11 July 2017]

[5] A.Y. Hoekstra and P.Q. Hung, “A quantification of virtual water flows between nations in relation to international crop trade,” *Water Research,* vol. 49, pp. 203–209, 2002.

[6] F. Gnehm, The Swiss Water Footprint Report A global picture of Swiss water dependence. pp. 36, Swiss, 2012.

[7] F. Pellicer-Martinez and J.M. Martinez-Paz, “The Water Footprint as an indicator of environmental sustainability in water use at the river basin level,” *Science of Total Environment*, vol. 571, pp. 561–574, 2016.

[8] A.Y. Hoekstra and M.M. Mekonnen, “The water footprint of humanity,” *PNAS,* vol. 109, pp. 3232–3237, 2011.

[9] D. Lovarelli, J. Bacenetti and M. Fiala, “Water Footprint of crop productions: A review,” *Science of Total Environment,* vol. 548-549, pp. 236–251, 2016.

[10] Water Footprint Network, WFN, 2014. Available: http: //http://waterfootprint.org/. [Accessed 20 May 2017]

[11] A.Y. Hoekstra and P.Q. Hung, “Globalisation of water resources: International virtual water flows in relation to crop trade,” *Global Environmental Change*, vol. 15, pp. 45–56, 2005.

[12] A.K. Chapagain, A.Y. Hoekstra, H.H.G. Savenije and R. Gautam, “The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries,” *Ecological Economics,* vol. 60, pp. 186–203, 2006.

[13] A.Y. Hoekstra and A.K. Chapagain, “Water footprints of nations.Water use by people as a function of their consumption pattern,” *Water Resources Management,* vol. 21, pp. 35–48, 2007.

[14] A.K. Chapagain and S. Orr, “An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes,” *Journal of Environmental Management,* vol. 90, pp. 1219–1228, 2009.

[15] K. Feng, Y.L. Siu, D. Guan and K. Hubacek, “Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: A consumption based approach,” *Applied Geography,* vol. 32, pp. 691–701, 2012.

[16] D. Guan and K. Hubacek, “Assessment of regional trade and virtual water flows in China,” *Ecological Economics,* vol. 61, pp. 159–170, 2007.

[17] I. Cazcarro, R.D. Pac and J. Sánchez-Chóliz, “Water consumption based on a disaggregated social accounting matrix of huesca (Spain),” *Journal of Industrial Ecology,* vol. 14, pp. 496–511, 2010.

[18] Y. Yu, K. Hubacek, K. Feng and D. Guan, “Assessing regional and global water footprints for the UK,” *Ecological Economics*, vol. 69, pp. 1140–1147, 2010.

[19] Z.Y. Zhang, M.J. Shi, H. Yang and A. Chapagain, “An input-output analysis of trends in vitual water trade and the impact on water resources and uses in China,” *Economic Systems Research,* vol. 23, pp. 431–446, 2011.

[20] H. Dong, Y. Geng, J. Sarkis, T. Fujita, T. Okadera and B. Xue, “Regional water footprint evaluation in China: A case of Liaoning,” *Science of Total Environment*, vol. 442, pp. 215–224, 2013.

[21] T. Okadera, Y. Geng, T. Fujita, H. Dong, Z. Liu, N. Yoshida and T. Kanazawa, “Evaluating the water footprint of the energy supply of Liaoning

Province, China: A regional input-output analysis approach," *Energy Policy,* vol. 78, pp. 148–157, 2015.

[22] T.C. Official Gazette, Water Polllution Control Procedure, Ankara, Turkey, 2004. Available: http://www.mevzuat.gov.tr/Metin.Aspx?MevzuatKod=7.5.7221&sourceXmlSearch=&MevzuatIliski=0 [Accessed 20 May 2017]

[23] American Public Health Association, American Water Works Association, Standard Methods for the Examination of Water and Wastewater, USA, 1999.

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

[25] E. Gomez-Llanos, P. Duran-Barroso and A. Matías-Sanchez,"Management effectiveness assessment in wastewater treatment plants through a new water footprint indicator," *Journal of Cleaner Production*, vol. 198, pp. 463-471, 2018.

[26] I. Martínez-Alcala, F. Pellicer-Martínez and C. Fernandez-Lopez, "Pharmaceutical grey water footprint: Accounting, influence of wastewater treatment plants and implications of the reuse," *Water Research*, vol. 135, pp. 278-287, 2018.

[27] L. Shao and G.Q. Chen, "Water footprint assessment for wastewater treatment: method, indicator, and application," *Environmental Science & Technology*, vol. 47, pp. 7787-7794, 201.