A case study of the conversion of grey water to a flush water source in a Turkish student residence hall

E. Giresunlu and B. Beler Baykal

ABSTRACT

A case study of the conversion to grey water to a flush water source in a student residence hall of the Turkish megacity Istanbul is presented. Grey water from bathtubs/showers and washbasins is treated and reused for flushing toilets. Raw and membrane bio-reactor (MBR) treated grey water quality was monitored throughout one academic year using parameters to characterize organic matter (COD/BOD), suspended solids (TSS/VSS), nutrients (N/P) and microbiological indicators (total/fecal coliform, *Escherichia coli*, *Enterococcus*). For raw grey water, all mean concentrations are below the characteristic concentrations for weak conventional domestic wastewater in terms of physicochemical parameters. However, total coliform concentrations were 7 logs, which is compatible with weak/intermediate conventional domestic wastewater and the mean concentration of fecal coliforms was 6 logs, corresponding to intermediate/strong conventional domestic wastewater. Results of this work revealed that organic matter and microbiological indicators were the important pollutants for this specific grey water. After treatment in an MBR system, grey water quality complied with standards given for reuse as flush water. The student residence hall was a successful example of conversion to grey water as a flush water source. As such, 25% of the wastewater could be revaluated and 25% of the regular daily water supply could be saved.

Key words | characterization, grey water, stream segregation, treatment, water reuse

E. Giresunlu (corresponding author)
B. Beler Baykal
Department of Environmental Engineering,
Istanbul Technical University,
Ayazaga 34469,
Istanbul,
Turkey
E-mail: *esragiresunlu@gmail.com*

INTRODUCTION

Water scarcity and deterioration of water quality are two of the major problems the world is facing today. These challenging concerns have been forcing people to search for alternative sources of water. In addition to conventional domestic wastewater which is considered one of those alternative sources, segregated streams of domestic wastewater have also been considered in recent years. Grey water, one of the streams which excludes toilet wastewater but includes all other domestic wastewater fractions, comprises 75% of the entire domestic wastewater by volume (Otterpohl *et al.* 2003), but has a lower pollution potential as compared with other streams and conventional domestic wastewater itself (Hernández Leal *et al.* 2011), as 41% of organic matter, 3% of nitrogen, and 10% of phosphorus in conventional domestic wastewater is contained in 75% of the total volume (Beler Baykal 2015). Stream segregation allows the further use of each stream in accordance with its characteristics and grey water is used potentially as an alternative source of water which at this time is mostly used for toilet flushing and irrigation. However with proper treatment, it can be reused for meeting the demand for every non-potable application.

Depending upon where it is collected from, grey water may also be segregated in two fractions: light grey water from baths/showers and washbasins with a lower pollution potential, and dark grey water from sinks, dishwashers and washing machines with a higher level of pollution (Birks & Hills 2007). Light grey water makes up about 30–40% of the entire grey water stream, which more or less corresponds to the flush water use in Turkey (Giresunlu & Beler Baykal

doi: 10.2166/ws.2016.078

2014), which was calculated from mass balances based on unit water use expected for various household functions and habits of a typical Turkish household. According to Table 1, which shows some typical characteristics of grey water, the pollution potential of mixed grey water is higher compared with the light fraction. A survey of the table reveals that the level of nutrients are low, however organic matter is high. The primary concern in grey water treatment is organic matter (Al-Balawenah *et al.* 2010), however a fast survey of Table 1 also reveals that microbiological indicator concentrations are considerable.

Although stream segregation is a concept of the 2000s, there have been considerable efforts around the world led by Australia and Germany along with other countries, to make use of this alternative resource (Allen *et al.* 2010). However, grey water reuse is a practice which has only recently been appearing in the agenda of Turkey.

Table 1 | Typical grey water characteristics

		Mixed[a]	Light	
	Unit	House[b]	House[c]	Student residence hall[d]
COD	mg/L	245	112	96
sCOD	mg/L	177	29	
BOD	mg/L	90	78	46
sBOD	mg/L			31
TSS	mg/L	48	37	39
VSS	mg/L	39		
TKN	mg/L	9	5.4[e]	4.6
NH_4-N	mg/L			
TP	mg/L	7.3	0.2	0.9
PO_4-P	mg/L			
pH				
Turbidity	NTU		49.5	26
Total coliform	cfu/100 mL	1.36E + 04		2.20E + 08
Fecal coliform	cfu/100 mL	3.57E + 03		
E. coli	cfu/100 mL		3.00E + 04	3.90E + 05
Enterococcus	cfu/100 mL		8.50E + 03	2.50E + 03

[a]Mixed refers to grey water generated from wash basins, bathtubs/showers together with kitchen sinks.
[b]Atasoy *et al.* (2007).
[c]Chaillou *et al.* (2011).
[d]Birks & Hills (2007).
[e]Total nitrogen.

Istanbul, the biggest city in Turkey and one of the megacities of the world, has a population of 14.3 million (TUIK 2015) and houses about 50% of the Turkish industry (Dogan 2013). The megacity is far from supplying the water demand from nearby resources and a large portion of the demand is provided through interbasin water transfer. The largest portion of the water with 20% of total demand is brought from Buyuk Melen (ISKI 2016), which is 200 km away from the city. The amount of water brought from this water resource more or less corresponds to the water demand for flushing the toilets in the city.

One of the municipality student residence halls in Istanbul was identified as the locale of a working example of grey water reclamation/reuse. Accordingly, its infrastructure was reconstructed to segregate and reclaim this domestic wastewater fraction. Grey water from bathtubs/showers and washbasins are collected and treated to be reused for flushing toilets in the building.

The aim of this work was to analyze the characteristics of grey water collected and to monitor the effluent quality of the membrane bio-reactor (MBR) to avoid any possible health problems that could arise. Samples were taken from the equalization tank outlet and from the effluent of the MBR. Parameters to characterize organic matter (COD/BOD), suspended solids (TSS/VSS), nutrients (N/P) and microbiological indicators (total/fecal coliform, *Escherichia coli*, *Enterococcus*) were analyzed for a period of 8 months, which covered the academic year.

MATERIALS AND METHODS

Study area

The infrastructure of the residence hall was reconstructed to segregate and reclaim grey water. Within this context, the pipeline assembly was renewed to collect the grey water from bathtubs/showers and washbasins of all bathrooms in the building. The residence hall serves 232 female university students in 72 rooms, each of which is equipped with a bathroom. Grey water stream from bathtubs/showers and wash basins is treated and reused for flushing toilets. The treatment system is installed in the basement of the building.

Grey water reclamation scheme consists of an equalization tank, a coarse screen and an MBR system, as shown in Figure 1. Grey water is collected in a tank that also serves an equalization purpose and then it is pumped through a coarse screen. The effluent from the coarse screen is treated in an MBR, which is equipped with submerged ultrafiltration. Effluent of MBR is collected in a treated water storage tank, which serves as the water supply tank for flushes. A tap water intake is also installed to make up for any deficiency of the grey water to be used as the flush water and in case of a deficiency the gap is made up for through tap water use.

Sampling

The samples were taken from the outlet of the grey water collection tank to characterize raw grey water and to investigate quality changes within the inlet stream. The effluent quality from the entire treatment system was also monitored to evaluate system performance. Sampling points, which are marked as SP, are shown in Figure 1.

Sampling was done as grab sampling and the samples were placed in sterilized 2 L plastic bottles. All samples were taken between 10 and 11 am to allow the equalization of grey water in the collection tank, which is generated due to the morning showers before the students leave for school. Sampling was carried out once a month during the weekdays to ensure that practically all of the students are in the residence hall, to monitor monthly changes and at the same time to be consistent in terms of possible diurnal variations. No samples were taken during weekends, mid-term breaks, summer breaks and holidays. A total of eight samples were taken and analyzed in an academic year. All analyses were started within 2 hours following sampling.

Analysis

Both raw and treated grey water quality was investigated through 10 physicochemical parameters. Organic matter concentrations were investigated with chemical oxygen demand (COD), soluble COD (sCOD), biochemical oxygen demand (BOD) and soluble BOD parameters (sBOD). Total suspended solids (TSS) and volatile suspended solids (VSS) parameters were used for characterization of the grey water in terms of solid matter, while ammonium (NH_3-N), total Kjeldhal nitrogen (TKN), orthophosphate (PO_4-P) and total phosphorus (TP) were the physicochemical parameters analyzed for the detection of nutrients. For COD and sCOD parameters, ISO 6060 (1989) method was used, while for all other physicochemical parameters standard methods were employed.

Organic matter seems to be the most widely used parameter in the characterization of grey water. However, maintaining public health is an important issue and it was decided to investigate the microbiological quality of raw and treated grey water to assure hygienic safety. Total coliform, fecal coliform, *E. coli* and *Enterococcus* were the microbiological indicators investigated for both raw and treated grey water samples. The former two were selected as they are the most widely used conventional parameters for detection of microorganisms in water (European Union 1998; Turkish Standards 2005), while the latter two were monitored in accordance with the recent recommendations of WHO (1999) and EPA (1997) as they have a better correlation with diseases. Analyses were carried out according to ISO 8199 (2005).

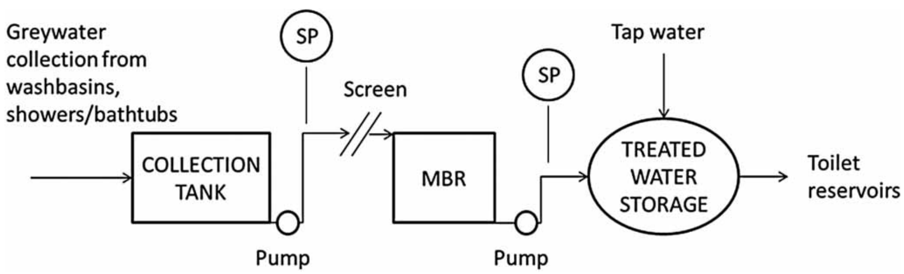

Figure 1 | Grey water management system in student residence hall.

RESULTS AND DISCUSSION

Both raw and treated grey water were of interest in this work, therefore monitoring of both have been undertaken simultaneously throughout this investigation.

Raw grey water

Results of raw grey water monitoring are summarized in Table 2, together with conventional domestic wastewater characteristics (Tchobanoglous *et al.* 2003). Table 2 reveals that the quality of light grey water generated from the student residence hall is compatible with weak conventional domestic wastewater. Exceptions are maximum COD, TSS and VSS, however all mean concentrations are below the characteristic concentrations for weak conventional domestic wastewater in terms of physicochemical parameters.

The concentration change within a year in terms of organic matter for raw grey water is shown in Figure 2, which reveals that sCOD, BOD and sBOD concentrations did not change across a wide range, while COD concentrations fluctuated. The average BOD/COD ratio was calculated as 35%, which was somewhat lower than conventional domestic wastewater. sCOD was 39% of COD concentration, indicating that 61% of organic matter was in particulate form in this particular light grey water. Also sBOD/BOD ratio was found as 26%, which means that most of the organic matter which was biodegradable under BOD test conditions was also in particulate form.

Figure 3 shows the TSS and VSS concentrations in student residence hall grey water. Results obtained from this work revealed that TSS and VSS concentrations in raw grey water showed a similar trend and most of the suspended solids were in volatile/organic form, based on the VSS/TSS ratio of 66%.

The raw grey water investigated was very low in terms of nutrient content. It may be observed from Table 2 that even the maximum values of nutrients measured in the grey water under investigation were considerably lower than even weak conventional domestic wastewater. This is especially apparent for nitrogen. With these results it was concluded that nutrients would not be considered as a major parameter for reuse of grey water.

Table 2 | Characteristics of raw grey water for the student residence hall

		Raw grey water				Conventional domestic wastewater[a]		
	Unit	**Min**	**Max**	**Mean**	***n*[b]**	**Weak**	**Intermediate**	**Strong**
COD	mg/L	99	351	198	8	250	430	800
sCOD	mg/L	59	94	85	6			
BOD	mg/L	54	85	67	8	110	190	350
sBOD	mg/L	18	24	20	7			
TSS	mg/L	56	186	139	8	120	210	400
VSS	mg/L	50	110	94	8	95	160	315
TKN	mg/L	4.05	11.47	6.09	8	20[b]	40[b]	70[b]
NH_4-N	mg/L	0.43	0.86	0.64	8	8	15	25
TP	mg/L	1.61	2.01	1.78	8	4	7	12
PO_4-P	mg/L	0.57	0.92	0.75	8	1	2	4
Total coliform	cfu/100 mL			1.16×10^7	2	10^6–10^8	10^7–10^9	10^8–10^{10}
Fecal coliform	cfu/100 mL			4.82×10^6	2	10^3–10^5	10^4–10^6	10^5–10^8
E. coli	cfu/100 mL			2.11×10^6	2			
Enterococcus	cfu/100 mL			0	2			

[a]Tchobanoglous *et al.* (2003).
[b]*n*, number of samples.

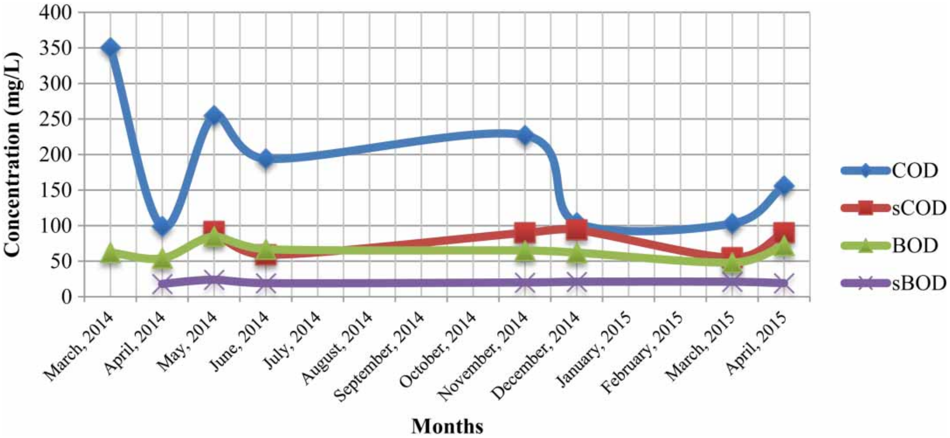

Figure 2 | Organic matter concentrations in raw grey water.

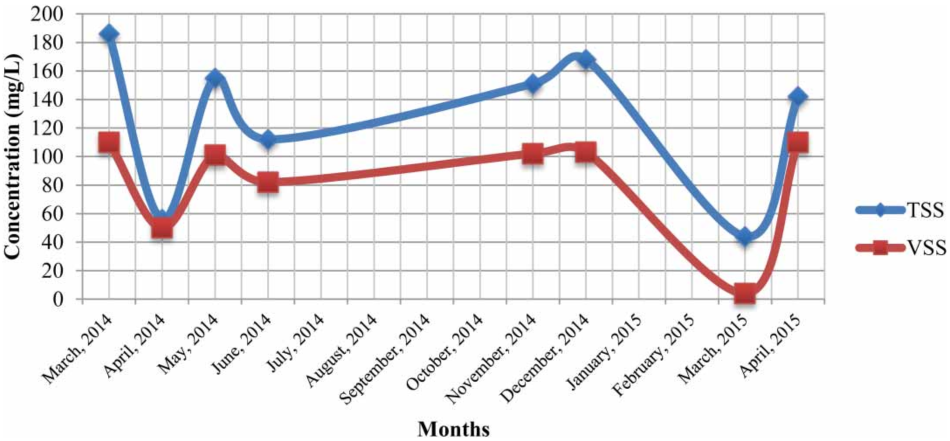

Figure 3 | Suspended solids concentrations in raw grey water.

The raw grey water samples collected from the student residence hall have more pollution potential in terms of COD and TSS as compared with the light grey water characteristics, especially the light grey water from the student residence hall, given in Table 1. These differences arise due to the source of grey water collected. As only washbasin and bath/shower grey water was collected rather than all domestic wastewater, the pollutant concentrations are lower compared with conventional domestic wastewater. However, as the building serves girls only, the frequency of the use of personal care products is higher together with possible depilation in the showers, ending up with more polluted grey water in terms of organic matter and suspended solids. Also, as there is no kitchen in the building which is available for the use of students, dishwashing activities are carried out in the washbasins, which are connected to the grey water collection system. Dishwashing in washbasins introduces food residue into the grey water, causing higher concentrations of both organic matter and suspended solids.

Considering microbiological quality, as grey water does not come in contact with toilet wastewater which contains the majority of pathogens due to segregation, relatively low pollution potential in terms of microbiological indicators were expected. However total coliform concentration of light grey water was found as 7 logs, which is compatible with weak or intermediate conventional domestic wastewater. Moreover, the mean concentration of fecal coliform is found as 6 logs, which corresponds to intermediate or strong conventional domestic wastewater. These results show that microbiological quality and monitoring of microbiological indicators are crucial to secure hygienic safety when the reuse of grey water is considered.

Treated grey water

Results of the analyses carried out for organic matter and suspended solids at the effluent of the MBR are given in graphical form in Figures 4 and 5. A summary of the results and the standards and guidelines used for toilet flushing with treated grey water around the world are presented in Table 3. The results obtained reveal that even the maximum concentrations of pollutants at the effluent of the treatment system fit with the standards used for grey water reuse in toilet reservoirs for both physicochemical parameters and microbiological indicators.

According to the analyses carried out with treated grey water, COD concentrations were always below 30 mg/L, which is the lower limit of detection for the analysis technique used. Also, BOD concentrations were never above 5 mg/L, which is the lowest advised by the aforementioned standards. Maximum TSS and VSS concentrations were 8 and 7 mg/L, respectively. This shows that even the maximum TSS value measured was below the requirement of all standards considered.

Removal efficiencies in terms of BOD, TSS and VSS were calculated as 95, 96 and 98%, respectively. The effluent quality of an MBR treating conventional domestic

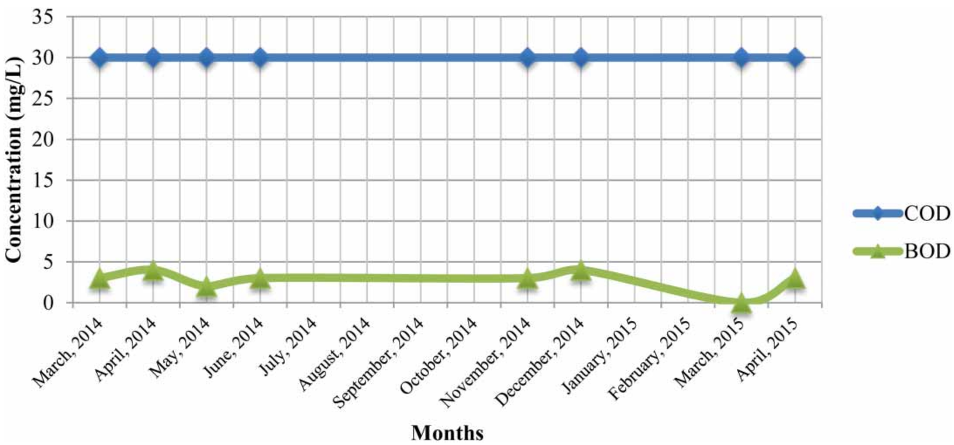

Figure 4 | Organic matter concentrations in treated grey water.

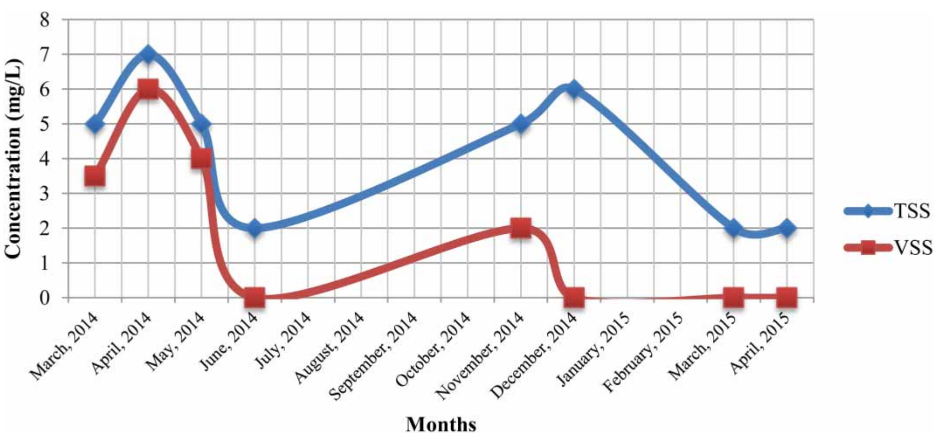

Figure 5 | Suspended solids concentration in treated grey water.

Table 3 | Treated grey water quality and the standards and guidelines for toilet flushing

						Standards for toilet flushing					
		Treated grey water quality				Australia					
	Unit	Min	Max	Mean	n^a	QLD[b]	VIC[c]	WA[d]	NSW[e]	GER[f]	WHO[g]
COD	mg/L	<30	<30	<30	8		Not permitted				
BOD	mg/L	2	4	3	8	10		10	20	5	10
TSS	mg/L	2	7	5	8	10		10	30		10
VSS	mg/L	0	6	2	8						
TKN	mg/L	0.56	2.32	1.22	8						
NH_4-N	mg/L	0	0.2	0.09	8						
TP	mg/L	0.57	1.39	0.97	8						
PO_4-P	mg/L	0.21	0.81	0.51	8						
pH						6.5–8.5		6.5–8.5			
Turbidity	NTU					1		1			
Cl^-	mg/L					0.2–1.0		0.2–1.0		<1	
Total coliform	cfu/100 mL			0	2					10	10
Fecal coliform	cfu/100 mL			0	2						
E. coli	cfu/100 mL			0	2	1		1	10		
Enterococcus	cfu/100 mL			0	2						

[a]*n*: Number of samples.
[b]Queensland (Queensland Government 2011).
[c]Victoria (EPA Victoria 2013).
[d]Western Australia (Government of Western Australia 2010).
[e]New South Wales (New South Wales Government 2008).
[f]Germany (Nolde 1996).
[g]World Health Organization (WHO 2006).

wastewater is expected to provide COD, BOD and TN concentrations less than 30, 5 and 10 mg/L, respectively (Tchobanoglous *et al.* 2003). The results reveal that the effluent quality of the MBR at the student residence hall are also compatible with these values.

The microbiological indicators analyzed were always zero in the treated grey water samples tested. This can be attributed to the pore size of ultrafiltration membranes, which is smaller than the size of the microbiological indicators tested. The filtration process is capable of removing those indicators and the effluent was free of indicators during sampling.

As the building serves students dominantly during morning and evening hours, the typical water consumption was not similar to typical domestic water usage. The staff in charge indicated that daily water usage in the student residence hall in bathtubs/showers and washbasins was about 5 m^3, while the water needed to flush the toilets was about 5.6 m^3 daily. This shows that there is a 0.6 m^3 gap and this is compensated by an intake of tap water, which is added to the treated grey water storage tank supplying water for toilet flushes. When the amount of treated grey water is less than the amount of water needed to flush the toilets, the tap water intake works automatically.

CONCLUSION

Monitoring raw grey water at the university residence hall showed that the pollution potential in terms of physicochemical parameters is lower compared with weak conventional domestic wastewater. On the other hand, microbiological quality of raw grey water is comparable with weak conventional domestic wastewater in terms of total coliforms, while it may be comparable with intermediate and strong conventional domestic wastewater in terms of fecal coliforms. The sources which the grey water collected from, high personal care product usage and possible dish-washing activities in washbasins connected to the grey water collection system, are considered as the reasons of the differences in terms of quality, as compared with domestic wastewater and the literature regarding light grey water.

Standards related to water and grey water reuse reveals that raw grey water reuse is not applicable if it is not treated. However, a proper treatment system solves the problems both in terms of physicochemical parameters and microbiological indicators. The outflow quality of the MBR in the student residence hall always complies with the standards for toilet flushing.

Taking into consideration all results regarding physicochemical parameters, searching for the possible use of filtration/membrane filtration as an alternative treatment unit may also be a topic of research.

The student residence hall investigated was observed to be a successful example of conversion to grey water as a flush water source and hence reclamation and reuse of grey water. No health problems were reported and no complaints were made regarding loss of comfort by the students/users in the residence hall since the onset of this revision. With this practice, 25% of the wastewater could be revaluated, similarly 25% of the regular daily water supply could be saved through conversion to grey water as the flush water source.

REFERENCES

Al-Balawenah, A., Al-Karadsheh, E. & Qadir, M. 2010 Community-based reuse of greywater in home farming. In: *International Conference on Food Security and Climate Change in Dry Areas*, 1–4 February 2010, Amman, Jordan.

Allen, L., Christian-Smith, J., Palaniappan, M. & Pacific Institute 2010 *Overview of Greywater Reuse: The Potential of Greywater Systems to Aid Sustainable Water Management*. Pacific Institute, CA, USA.

Atasoy, E., Murat, S., Baban, A. & Tiris, M. 2007 Membrane bioreactor (MBR) treatment of segregated household wastewater for reuse. *Clean* **35** (5), 465–472.

Beler-Baykal, B. 2015 Stream segregation in household use: a review of grey water as an alternative source of water and yellow water as an alternative source of fertilizers. *Water Qual. Expo. Health* **7** (1), 27–37.

Birks, R. & Hills, S. 2007 Characterization of indicator organisms and pathogens in domestic greywater for recycling. *Environ. Monit. Assess.* **129** (1), 61–69.

Chaillou, K., Gérente, C., Andrés, Y. & Wolbert, D. 2011 Bathroom greywater characterization and potential treatments for reuse. *Water Air Soil Pollut.* **215** (1), 31–42.

Dogan, M. 2013 Industrialization process in Istanbul from past to present and its development over the last decade. *Marmara Cografya Dergisi* **27** (1), 511–550 (in Turkish).

EPA 1997 *Volunteer Stream Monitoring: A Methods Manual*. Office of Water-Monitoring. Environmental Protection Agency, USA.

EPA Victoria 2013 *Code of Practice Onsite Wastewater Management*. Environment Protection Authority, Victoria.

European Union 1998 *Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption*. European Union, Belgium.

Giresunlu, E. & Beler-Baykal, B. 2014 A preliminary investigation on pathogenic indicators in segregated domestic wastewater streams. In: *12th IWA Specialist Conference on Small Water and Wastewater Systems & 4th IWA Specialist Conference on Resource Oriented Sanitation*, 2–4 November 2014, Muscat, Sultanate of Oman.

Government of Western Australia 2010 Code of Practice for the Reuse of Greywater in Western Australia 2010. Government of Western Australia Department of Health, Western Australia.

Hernández Leal, L., Temmink, H., Zeeman, G. & Buisman, C. J. N. 2011 Characterization and anaerobic biodegradability of grey water. *Desalination* **270** (1), 111–115.

ISKI 2016 *The amount of water supplied from Melen and Yesilcay*. Istanbul Water and Sewerage Administration. Available from: www.iski.gov.tr (in Turkish).

ISO 6060 1989 *Water Quality–Determination of the Chemical Oxygen Demand*. International Organization for Standardization, Switzerland.

ISO 8199 2005 *Water Quality–General Guidance on Numeration of Microorganisms by Culture with Membrane Filtration*. International Organization for Standardization, Switzerland.

New South Wales Government 2008 *New South Wales Guidelines for Greywater Reuse in Sewered, Single Household Residential Premises*. New South Wales Department of Energy, Utilities and Sustainability, New South Wales, Australia.

Nolde, E. 1996 Wasserrecycling in 4-Sterne Hotel. *Wasserwirtsch. Wassertech.* **6**, 39–41.

Otterpohl, R., Braun, U. & Oldenburg, M. 2003 Innovative technologies for decentralized water wastewater and biowaste management in urban and peri-urban areas. *Water Sci. Technol.* **48** (11), 23–31.

Queensland Government 2011 *Queensland Plumbing and Wastewater Code*. Department of Housing and Public Works, Queensland, Australia.

Tchobanoglous, G., Burton, F. L., Stensel, H. D. & Metcalf & Eddy 2003 *Wastewater Engineering: Treatment and Reuse*, 4th edn. McGraw-Hill, Boston.

TUIK 2015 *Turkish Statistical Institute Database*. Available from: www.turkstat.gov.tr/Start.do. (accessed 15 September 2015).

Turkish Standards 2005 *TS266 Regulations for water intended for human consumption*, Turkey (in Turkish).

WHO 1999 *Health-based Monitoring of Recreational Water: The Feasibility of a New Approach (The Annapolis Protocol)*. World Health Organization, Geneva, Switzerland.

WHO 2006 *Overview of Greywater Management Health Considerations*. Regional Office for the Eastern Mediterranean Centre for Environmental Health Activities Amman, Jordan.

First received 27 January 2016; accepted in revised form 21 April 2016. Available online 25 May 2016