GREY WATER RECYCLING FOR REUSE IN TOILET FLUSHING: A CASE STUDY IN THAILAND

Wannawit Taemthong[1]

ABSTRACT

Grey water from washbasins represents the least polluted source of waste water in households and buildings. This research study investigated three alternatives in recycling grey water from washbasins for reuse in toilet flushing systems. Grey water was collected from the washbasins of a nine-storey university building. The water was treated employing three distinct treatment systems in order to determine the most appropriate system when reusing such water in flushing systems. The grey water treatment systems under scrutiny were composed of a sedimentation tank, a 24-hour aeration tank and a sand and carbon filtering tank, functioning in conjunction with a final sedimentation tank. The water quality from the selected treatment system had TSS, BOD_5, and Turbidity measures of 1.67 mg/l, 3.33 mg/l, and 3.33 NTU, respectively. Fecal coliform bacteria and E. Coli were not found in the treated water. Efficiency measures in reducing TSS, BOD_5, and Turbidity were 93%, 75%, and 91%, respectively. Fifty-five toilet users were interviewed during the experiment, sixty nine percent of which reported that the recycled water was comparable to tap water. In conclusion, this research recommends treating grey water from washbasins and reusing it in flushing systems in order to deploy water more efficiently in buildings.

KEYWORDS

building; grey water; recycle; washbasin; water efficiency

INTRODUCTION

Grey water refers to water which is slightly contaminated by human activities, but may be reused after suitable treatment (Liu et al., 2010). It derives from domestic washing from activities involving the use of washbasins, showers, baths, kitchen sinks, and washing machines, but excludes black water sourced from toilets and urinals (Jefferson et al., 1999; Liu et al., 2010). Using recycled grey water potentially enables practitioners to promote the preservation of high quality fresh water supplies and reduce pollutants in the environment, thus enabling reductions in potable water ranging from 28.7% to 34.8% (Ghisi and Ferreira, 2007; Liu et al., 2010). On site water treatment and the reuse of grey water represent the most interesting contemporary

1. King Mongkut's University of Technology North Bangkok, Department of Civil Engineering, 1518 Pracharad 1 Rd., Bangsue, Bangkok, 10800, Thailand, wannawit@gmail.com.

issues within wastewater recycling (Fountoulakis et al., 2016). Grey water recycling is a valuable alternative source of water for non-potable uses (Stec and Kordana, 2015). In this context, a university in Iran used the application of trickling filters with plastic media and Lika aggregates in treating grey water (Shamabadi et al., 2015). Chaillou et al. (2011) employed sand bed filtration, granular activated carbon, and chlorine in treating grey water derived from households. Their results were positive in terms of removing total suspended solids from treated water, reducing 30% of COD and significantly decreasing the microbial population. Zipf et al. (2016) studied different types of treatment systems and found that water quality when passed through an activated carbon filter after sand filtration was much better in terms of turbidity and surfactant removal compared to alternative systems. Leadership in Energy and Environmental Design (LEED), an acceptable practice in designing and building green buildings, demands a water usage reduction of 20% as a prerequisite (USGBC, 2009). If water usage can be reduced more than 40%, a building can earn a maximum of four credits within the water efficiency criteria. Waste water recycling, therefore, is considered intrinsic to designing effective green building systems. When considering all sources of grey water, it has been found that grey water from washbasins represents the least polluted source (Friedler, 2004). Toilet flushing was found to consume the highest percentage of potable water in a study of a multi-story residential building in Brazil, recording an average of 32.8% (Ghisi and Ferreira, 2007). Average domestic water consumption in the UK is 150 litres per head per day (Sutherland, 2008). Thus, approximately 49 litres per person per day could potentially be saved by using recycled grey water. This saving could be achieved by promoting the use of grey water in toilet flushing systems. However, to avoid health risks, grey water should be treated at a higher standard before reuse (Li et al., 2009). One objective of this research is, therefore, to find an appropriate grey water treatment for reusing the water from washbasins in the flushing systems of men's urinals and toilets.

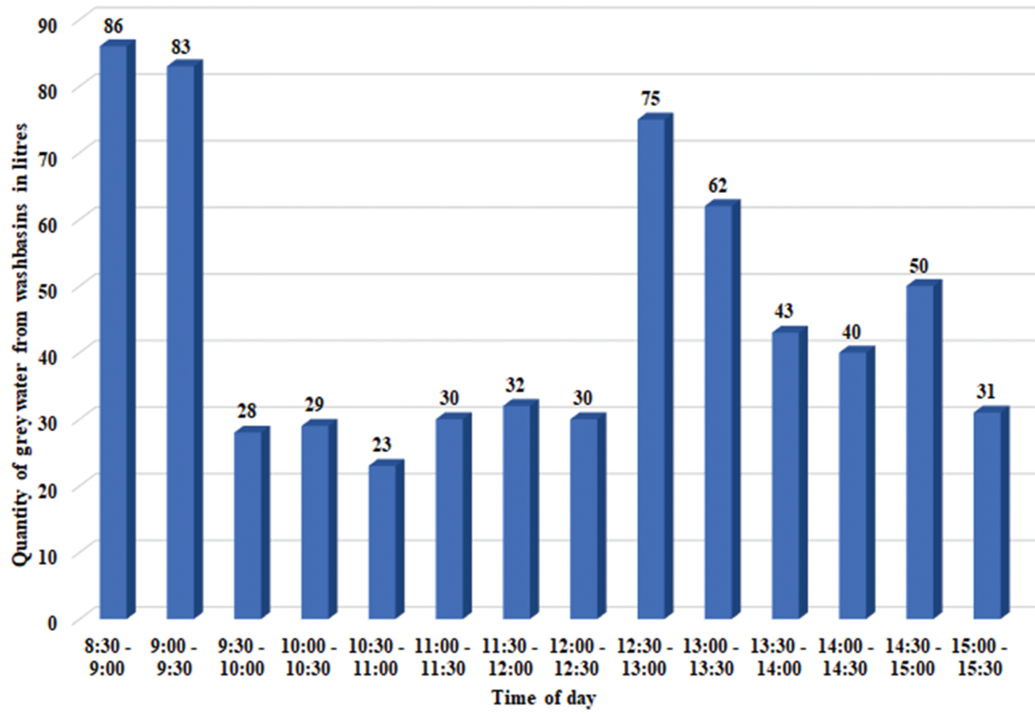
METHODOLOGY

The research was conducted at King Mongkut's University of Technology North Bangkok. Grey water was collected from all washbasins from the second to ninth floors of a nine-storey university building. The average grey water emission volumes are shown in Figure 1. Such averaged values were recorded at thirty-minute intervals from 8:30 to 15:30. The daily average discharge totalled 641 litres. Grey water discharge volumes are estimated roughly by measuring water height increase in grey water collection tanks. The average volumes allowed us to select an appropriate capacity treatment tank. In this case, an 800 litre tank was chosen.

The water was treated using three experimental systems in order to compare resultant water quality. A suggested system, which offers the best water quality, will run continuously for one subsequent month in order to observe water quality during two more tests. The three systems have different components and costs, as shown in Table 1.

The schematic design of a full system is shown in Figure 2. Water is received from washbasins and collected in a grey water accumulation tank. At this point, the water collected is tested to ascertain its quality in a laboratory and labeled as "*before treatment*." Then, the water was moved by pump and allowed to rest for 24 hours in a sedimentation tank. This water was then pumped to an aeration tank and kept under aerated conditions for an additional 24 hours. After this, the water was pumped to a sand and carbon filtering tank, containing two layers of material—sand and carbon filters. Subsequently, the water was pumped to be stored in a

FIGURE 1. Grey Water Discharge Rates at Varying Times of Day.



recycled water accumulation tank for later use in toilets and mens' urinal flushing systems. The water in the last accumulation tank was labeled as "*after treatment*" and was tested for quality. Therefore, the grey water was collected twice within each system. Water was tested in a laboratory according to American Water Works Association guidelines covering the five parameters of interest in this research. They comprise total suspended solids, fecal coliform bacteria, E. Coli, BOD_5, and turbidity.

TABLE 1. Components of Water Treatment Systems.

System Component Name	Descriptions	System		
		Full	Aerated	Sedimentation
Accumulation tank	800 litres	✓	✓	✓
Sedimentation tank	800 litres	✓	X	✓
Aeration tank	800 litres with air pump	✓	✓	X
Sand and carbon filter tank	20 cm. in Ø, 1.50 m. in height	✓	✓	✓
Recycled water accumulation tank	800 litres	✓	✓	✓
Total initial cost, $		1,414	1,193	908

Figures 3 and 4 show the schematic designs of aerated and sedimentation systems, respectively. They are similar to that employed in the full system. However, the aerated system does not have a sedimentation tank, while a sedimentation system does employ an aeration tank.

RESULTS

Water was tested according to the standard methods for the examination of water and wastewater of the American Water Works Association 2012. Tables 2, 3, and 4 show details of the water quality found in both the before and after treatments of the full, aerated, and sedimentation systems, respectively. The full system necessitates the highest investment cost at $1,414, since it comprises the full system of this research, as shown in Table 1. The use of this system resulted in a reduction of suspended solid goods at a rate of 90%, BOD_5 at –10%, and turbidity at 94%, as shown in Table 2. The most desirable characteristic of this system is its highest efficiency rates in decreasing suspended solids and turbidity. However, BOD_5 increased. The aerated system, which does not utilize a 24 hour sedimentation tank, was able to reduce suspended solids at 90%, BOD_5 at 78%, and turbidity at 75%. It incurs only a moderate investment cost of $1,193. The most notable characteristic of this system is its highest efficiency in decreasing the volumes of suspended solids and BOD_5. On the other hand, efficiency in reducing turbidity is only moderately acceptable. The sedimentation system involves the lowest investment cost at $908. It does not necessitate an aeration tank, which constitutes the most expensive component in the systems used in this research. When using this methodology, suspended solids were reduced at a rate of 82%, BOD_5 at 22%, and turbidity at 66%. However, fecal coliform bacteria and E. Coli were still found in water after completing this treatment. Preliminary results show that the aerated system was the most effective among the three alternatives. Therefore, the aerated system was selected for one month observation. During this period, the water recycling system ran every working day. The water quality values recorded are shown in Tables 5 and 6 for *before* and *after* treatments, respectively.

FIGURE 2. Schematic Flow of Grey Water from Washbasins to Reuse in the Flushing of a *Full* Treatment System.

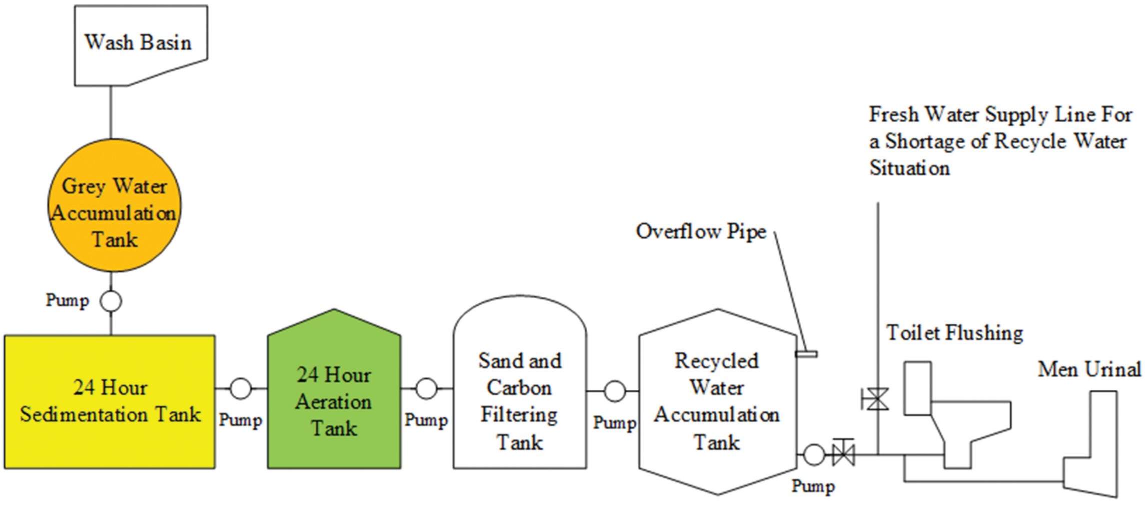


FIGURE 3. Schematic Flow of Grey Water from Washbasins to Reuse in the Flushing of an *Aerated* Treatment System.

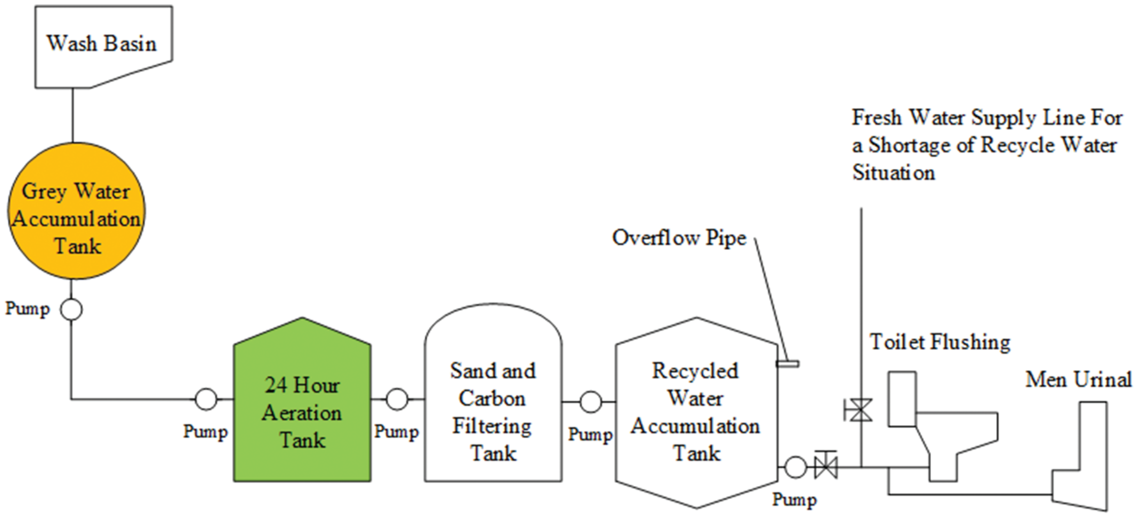
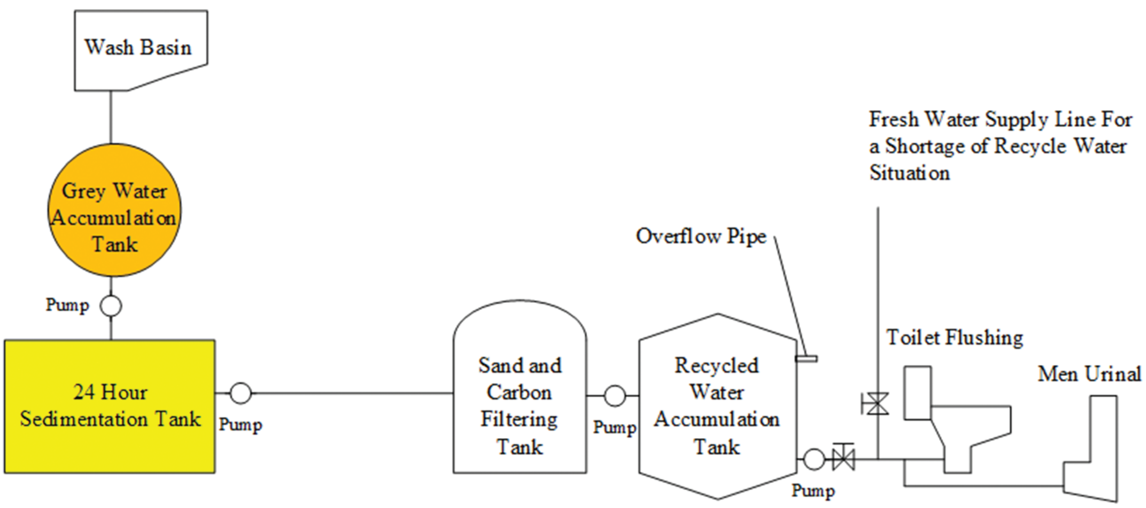


FIGURE 4. Schematic Flow of Grey Water from Washbasins to Reuse in the Flushing of a *Sedimentation* Treatment System.



Two more water samples were collected at the grey water accumulation tank. The water quality values recorded during this one month observation are labeled as test two and three, as shown in Table 5. Another two water samples were collected from the recycled water accumulation tank. They were tested and their water qualities shown in Table 6. The average efficiency rates of the aerated system in reducing SS, BOD_5, and Turbidity were measured at 93.04%, 75.02%, and 90.92%, respectively. Water quality parameters after the treatment of the aerated system are compared with certain country standards and shown in Table 7. The quality of the aerated system would be acceptable in Germany and New South Wales of Australia for reuse in

TABLE 2. Grey Water Quality Before and After Treatment of the Full System.

Test Parameter	Unit	Before Treatment		After Treatment	
		Visual characteristic	Values of each parameter	Visual characteristic	Values of each parameter
1. Suspended Solids	mg/L	White colour water with turbidity and suspended solids	31	Clear with no colour water and no suspended solids	3
2. Fecal Coliform Bacteria	MPN/100 mL		Not Found		Not Found
3. E. Coli	MPN/100 mL		Not Found		Not Found
4. BOD_5	mg/L		10		11
5. Turbidity	NTU		47		3

TABLE 3. Grey Water Quality Before and After Treatment of the Aerated System.

Test Parameter	Unit	Before Treatment		After Treatment	
		Visual characteristic	Values of each parameter	Visual characteristic	Values of each parameter
1. Suspended Solids	mg/L	Yellow clear water with suspended solids	20	Clear with no colour water with suspended solids	2
2. Fecal Coliform Bacteria	MPN/100 mL		Not Found		Not Found
3. E. Coli	MPN/100 mL		Not Found		Not Found
4. BOD_5	mg/L		18		4
5. Turbidity	NTU		16		4

TABLE 4. Grey Water Quality Before and After Treatment of the Sedimentation System.

Test Parameter	Unit	Before Treatment		After Treatment	
		Visual characteristic	Values of each parameter	Visual characteristic	Values of each parameter
1. Suspended Solids	mg/L	White colour water with turbidity and suspended solids	22	Yellow clear water with suspended solids	4
2. Fecal Coliform Bacteria	MPN/100 mL		Not Found		6
3. E. Coli	MPN/100 mL		Not Found		6
4. BOD_5	mg/L		18		14
5. Turbidity	NTU		49.5		17

TABLE 5. Grey Water Quality Before Treatment by Aerated System across Three Tests.

Test Parameter	Unit	Test results of each parameter *before* Treatment in 3 tests			Average	Median	Max
		1	2	3			
1. Suspended Solids	mg/L	20	20	32	24	20.00	32
2. Fecal Coliform Bacteria	MPN/100 mL	Not Found	Not Found	Not Found	Not Found	N/A	N/A
3. E. Coli	MPN/100 mL	Not Found	Not Found	Not Found	Not Found	N/A	N/A
4. BOD_5	mg/L	18	3	19	13.33	18.00	19
5. Turbidity	NTU	16	37	57	36.67	37.00	57

TABLE 6. Grey Water Quality After Treatment by Aerated System across Three Tests.

Test Parameter	Unit	Test results of each parameter *after* Treatment in 3 tests			Average	Median	Max
		1	2	3			
1. Suspended Solids	mg/L	2	2	1	1.67	2.00	2
2. Fecal Coliform Bacteria	MPN/100 mL	Not Found	Not Found	Not Found	N/A	N/A	N/A
3. E. Coli	MPN/100 mL	Not Found	Not Found	Not Found	N/A	N/A	N/A
4. BOD_5	mg/L	4	4	2	3.33	4.00	4
5. Turbidity	NTU	4	5	1	3.33	4.00	5

toilet flushing. It would fail in terms of the turbidity aspect in Brittish Columbia of Canada, Washington of USA, California of USA, and Victoria, of Australia. Coliform bacteria and E. Coli are not found in the three samples of the aerated system. SS and BOD_5 values are less than the limits specified in all of the countries shown. However, this research did not consider the effects of certain water parameters such as pH and chlorine residuals, which are required in certain countries, such as Canada, Japan, and Korea. Different countries have different guidelines. Economic and weather could be factors behind this.

Economic aspect

The aerated system has initial and yearly operating costs of $1,193 and $80, respectively, as shown in Table 8. They are less than the initial and yearly operating costs of the full system by 16% and 3% per year, respectively. Meanwhile, the aerated system is more expensive than

TABLE 7. Grey Water Quality Standards for Different Regions for Reusing Water in Toilet Flushing. (CMHC 2005)

Countries	SS (mg/L)	Coliform bacteria (CFU/100ml)	E. coli (CFU/100 ml)	BOD_5 (mg/L)	Turbidity (NTU)
British Columbia, Canada	≤ 5	≤ 2.2		< 10	≤ 2
California, USA		median < 2.2 and max ≤ 23			≤ 2
Germany		≤ 10	≤ 1	≤ 5	
New South Wales, AUS	≤ 30	median ≤ 10		≤ 20	
Victoria, AUS	≤ 5	median ≤ 10		≤ 10	≤ 2
Washington, USA	≤ 30	median ≤ 20		≤ 30	median ≤ 2 and max ≤ 5
This research	Max = 2	Not found	Not found	Max = 4	Max = 5 Median = 4

TABLE 8. Initial Investment, Yearly Costs and Benefits of the Three systems

Cash Flow Description	Cost of System		
	Full	Aerated	Sedimentation
Initial investment, $	1,414	1,193	908
Operating costs from electricity and sand and carbon filter, $ per year	82	80	52
Benefit from water saving, $ per year	69	69	69

the sedimentation system by 31% and 53% in terms of the initial and yearly operating costs, respectively.

The water saving is based on two major factors, volume of the grey water used each day and tank capacity. If the tank is too small, the grey water cannot be saved for later use and overflows through the drainage system of the building. Benefits from water saving is calculated using an average discharge at 641 litres per day for all systems. Thus, water could be saved at a rate of 176.3 m^3 per year, based on 275 working days per year in such a university building case. In this research, the benefit accrued from water saving is estimated at $69 per year, as shown in the last row of Table 8. This is calculated using the tap water unit cost in Bangkok being at $0.4 per m^3. These savings represent approximately 6.2% of average water usage, at 10.33 m^3 per day, based on the building from which our data was collected. The operating costs of the aerated system are higher than the benefits accrued from water saving, resulting in a negative cash flow. The rate of return cannot be determined in such a case. As a result, installing a water recycling system is not attractive in terms of an economic aspect. It is attractive for installing in a green building promoting environmentally-friendly practices in Bangkok. However, if a unit

TABLE 9. International Water Cost

Country	City	$/m^3	References
UK		2.00	(Anglian Water 2017)
USA	Boston	1.82	(Boston Water 2017)
Germany		1.78	(Daily Scandinavian 2016)
Denmark		1.72	(Daily Scandinavian 2016)
Thailand	Phuket	0.99	(PWA 2017)
Singapore		0.83	(Singapore 2017)
Thailand	Bangkok	0.41	(MWA 2017)

cost of tap water in Bangkok increases to $1.15 per m^3, the breakeven would be reached by a non-discounted method. Certain countries would find the recommended system attractive to install, including the UK, USA, Germany, and Denmark as shown in Table 9.

User opinion sample

Fifty-five toilet users were interviewed during the experiments. 83% of such users reported that the flushing water derived from the recommended recycling system did have some discoloration, but at an acceptable level. 67% percent of users reported that the recycled water was comparable to tap water. However, some factors were not included in this study such as odor or pathogens since most standards for reuse in flushing system do not require these measurements.

CONCLUSIONS AND DISCUSSION

The system recommended in this research is not economically viable enough on its own to attract users to install the system in their buildings in Thailand. However, it is suitable to be installed as the recommended system in green buildings seeking to reflect their corporate social responsibility and environmentally-friendly credentials. Since developers may well be interested in either earning green building credits or concerned about their environmental footprint, the water saving from using recycled water can be combined with using water saving faucets and valves and channelling rain water to landscaped areas in order to earn green building credits. The cost of implementing such credits as these is less expensive than that of some other credits. Fidar et al. (2010) confirmed that water as related to energy usage and toilet flushing systems play a significant role in reducing water consumption. Thus, water usage savings in toilet flushing systems could potentially help contribute towards both conserving our environment and earning credits according to LEED standards. In conclusion, the aerated system is effective for treating grey water derived from washbasins and reusing it in flushing systems. The recommended system represents a sufficiently efficient water treatment system which is adequate for recycling grey water from washbasin surplus especially. Water samplings were collected in Thailand. Therefore, the recommended system might be appropriate for a hot and humid climate area. The system could be implemented in schools, universities, or office building areas that emit approximately 600–1,000 litres volume of grey water on a daily basis. The area required for such an installation is approximately twelve square metres. In some buildings, fecal bacteria could be found, and for these instances adding chlorine to treat the grey water is recommended before use.

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REFERENCES

1. Anglian Water. (2017). "Anglian Water Services Ltd Homepage." <http://www.anglianwater.co.uk/household/your-account/bills-and-payments/tariffs/standard-rates/> (May 16, 2017).
2. Boston Water. (2017). "Boston Water and Sewer Commission Homepage." <http://www.bwsc.org/services/rates/rates.asp> (May 16, 2017).
3. Canada Mortgage and Housing Corporation (CMHC). (2005). "Water reuse standards and verification protocol." Canada Healthy housing and communities series.
4. Chaillou, K., Gerente, C., Andres, Y., and Wolbert, D. (2011) "Bathroom greywater characterization and potential treatments for reuse." *Water air and soil pollution*, 215, 31–42.
5. Daily Scandinavian. (2016). "The Daily Scandinavian Homepage." Highest Water Prices in the World, April 20, 2016. <https://dailyscandinavian.com/highest-water-prices-in-the-world/> (May 16, 2017).
6. Fidar, A., Memon, F.A., and Butler, D. (2010). "Environmental implications of water efficient microcomponents in residential buildings." *Science of the Total environment*, 408, 5828–5835.
7. Fountoulakis, M.S., Markakis, N., Petousi, I., and Manios, T. (2016). "Single house on-site grey water treatment using submerged membrane bioreactor for toilet flushing." *Science of the Total Environment*, 551–552, 706–711.
8. Friedler, E. (2004). "Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities." *Environmental Technology*, 25, 997–1008.
9. Ghisi, E., and Ferreira, D. F. (2007). "Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil." *Building and Environment*, 42, 2512–2522.
10. Jefferson, B., Laine, A., Parsons, S., Stephenson, T., and Judd, S. (1999). "Technologies for domestic wastewater recycling." *Urban Water*, 1, 285–292.
11. Li, F., Wichmann, K., and Otterpohl, R. (2009). "Review of the technological approaches for grey water treatment and reuses." Science of the Total Environment, 407, 3439–3449.
12. Liu, S., Butler, D., Memon, F.A., Makropoulos C., Avery, L., and Jefferson, B., (2010). "Impacts of residence time during storage on potential of water saving for grey water recycling system." *Water Research*, 44, 267–277.
13. MWA. (2017). "Metropolitan Waterworks Authority Homepage." Water Tariffs Effective December 1999. <https://www.mwa.co.th/ewt_news.php?nid=303.> (May 16, 2017).
14. PWA. (2017). "Provincial Waterworks Authority." PWA Water Tariff Rate. <http://en.pwa.co.th/contents/service/table-price.> (May 16, 2017).
15. Shamabadi, N., Bakhtiari, H., Kochakian, N., and Farahani M. (2015). "The investigation and designing of an onsite grey water treatment systems at Hazrat-e-Masoumeh University, Qom, Iran." *Energy Procedia*, 74, 1337–1346.
16. Singapore. (2017). "Singapore's National Water Agency." Water Price. <https://www.pub.gov.sg/watersupply/waterprice.> (May 16, 2017).
17. Stec, A., and Kordana, S. (2015). "Analysis of profitability of rainwater harvesting, gray water recycling and drain water heat recovery systems." *Resources, Conservation and Recycling*, 105, 84–94.
18. Sutherland, K. (2008). "Wastewater filtration: A future for grey water recycling." *Filtration and Separation*, April, 18–21.
19. U.S. Green Building Council (USGBC). (2009). "LEED for new construction and major renovations rating system." Washington DC, USGBC.
20. Zipf, M. S., Pinheiro, I. G., and Conegero, M. C. (2016). "Simplified greywater treatment systems: Slow filters of sand and slate waste followed by granular activated carbon." *Journal of Environmental Management*, 176, 119–127.