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The Application of Combined Phytoremediation Greywater Treatment in A Single House

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ABSTRACT A report showed 22% of households in Indonesia did not have a proper sanitation facility in 2018 and this caused the potential discharge of their wastewater directly to the surface water, thereby, polluting the water and its surrounding environment. The quality of water resources is also declining nationwide due to pollution and this affects the cost of water treatment, therefore, it is necessary to determine the most effective treatment method to reduce this pollution. However, one of the breakthroughs observed to have met the criteria of low cost, simple operation and maintenance, and energy-saving is greywater treatment using plants (phytotechnology) combined with solar ultraviolet (UV) system. This research was, therefore, conducted to evaluate the performance of the coupled greywater treatment and investigate the possibility of its implementation in the actual condition of a selected single house. Moreover, the physical treatment and phytoremediation were combined with solar disinfection treatment, and the units selected include a collection and sedimentation chamber, filter, phytoremediation, and solar disinfection chamber. The flowrate was measured based on the difference in water level over time while the influent and effluent quality was evaluated at the inlet of the sedimentation chamber and outlet of the disinfection chamber. The results showed the organic efficiency removal was up to 92% while the solids content was found to be high at 49% and the system was able to effectively remove the ammonia at 57% and reduce the pathogenic bacteria by 88%. Moreover, the treated water quality known as the effluent met all the requirements of the Provincial Regulation of Central Java No. 5 of 2012 and Class 3 standard (water for cultivation of plants and fisheries) of Indonesian Government Regulation No. 82 of 2001. However, it did not meet the standard for toilet flushing water according to the standard from U.K, U.S.A, and Australia. This means the treatment system was unable to produce an effluent with the ability to replace the water use indoor. Therefore, it is recommended that an advanced treatment system for greywater such as Submerged Membrane Bioreactor be applied to maximize the intake of treated greywater for indoor and outdoor uses.

KEYWORDS Greywater; Phytoremediation; UV-System; Treatment Plant; Irrigation Water.

1 INTRODUCTION

A report presented in 2018 showed 78% of households in Indonesia have a sanitation facility and the contamination of the surface water was likely associated with domestic wastewater (Kementerian Perencanaan Pembangunan Nasional Republik Indonesia, 2019). This consists of greywater which makes 50-70% of the total water consumed and blackwater and despite the high volume of greywater, it only contributes 30% of the organic fraction and 9-20% of the nutrients and several million bacteria and this makes it a good source for reusable water (Fountoulakis et al., 2016; Bute et al., 2017). The water demand in a household includes those required for drinking, kitchen, bath, flushing of the toilet, and garden irrigation and those associated with toilet flushing and garden irrigation have been reported to be responsible for 20-30% and 10%-20% respectively of the water consumption in the household (Oh et al., 2018; Prathapar et al., 2005). A source with good quality is preferred for drinking, kitchen, and bathwater while reusable water is allowed for the flushing of toilet and garden irrigation (Dolnicar, Hurlimann, and Grün, 2010). This means it is possible to use the greywater from every household to support the water demand for toilet flushing and garden irrigation and this is expected to reduce the demand for fresh water supplies as well as the amount of wastewater discharged into the environment (Marleni and Raspati, 2020). Therefore, greywater recycling represents a plausible system-level approach to achieve greater water sustainability and resiliency (Ma et al., 2015).

Greywater contains lesser contaminants compared to blackwater but has the ability to cause a hazard when used untreated, therefore, there is a need for its treatment before utilization. Several studies have, however, applied or reviewed the treatment of greywater to select the best method based on the usage while some focused on the physical, chemical, and biological treatment and the combination of physical and biological treatment. A study showed the single application of physical treatment processes only is sufficient for greywater with deficient organic strength at <280 mg/L (Li, Wichmann, and Otterpohl, 2009). Moreover, a submerged membrane bioreactor was applied in a single house and proven effective in filtering the fine particulate, removing the pathogens, and reducing the organics and nutrients (Fountoulakis et al., 2016) but its operation and maintenance are not easy due to the need to change some of its spare parts once in a while. Biological treatment systems also often have some problems such as the formation of foam and inefficient sludge settling which usually leads to the deterioration of their performance (Bradley et al., 2002). Therefore, only a few households have the ability to apply this treatment because it is expensive and require extra effort to keep the membrane running smoothly. Biological treatment depends on the ratio of BOD/COD and since greywater mostly has a higher rate of these characteristics with nutrient efficiency, it serves as a limitation to the use of this method (Jefferson et al., 2000).

Chemical treatment such as the addition of aluminum sulfate $(Al_2(SO_4)_3$ has also been applied to treat the colloidal matters in the greywater (Li, Wichmann and Otterpohl, 2009) but it requires analysis to determine the appropriate dosage. This is considered to be costly based on the expenses of chemicals and the space for storage. Moreover, it is discovered not to be suitable for garden irrigation due to the need for water with fewer chemicals in ensuring plant growth.

The on-site household greywater treatment and reuse system required in most cases is usually expected to have a robust daily variation of greywater load, high pollutant removal efficiency, simple operation and maintenance, and easily monitored by the inhabitants. Phytoremediation method is a natural process which involves the application of plants on greywater treatment and has been confirmed to be cost-effective, easy to operate and maintain, stable, and robust (Arden and Ma, 2018; Chandekar and Godboley, 2015; Laaffat, Ouazzani, and Mandi, 2015; Bute et al., 2017). Moreover, contaminants are absorbed by macrophytes and stored in the macrophytes shoot and leaves during the phytoremediation process (Bute et al., 2017).

Phytoremediation has the ability to remove organic and nutrients but its ability to remove or deactivate pathogens considered to be important to human health is still being questioned (Arden and Ma, 2018; Oh et al., 2018). Therefore, it is necessary to combine the method with another disinfection treatment which is expected to be selected using certain criteria such as ease of operation and maintenance, cost-effectiveness, and robustness (Marleni, Ermawati, and Firdaus, 2020). The disinfection with natural U.V. from sunlight is considered a clean treatment with high pathogen removal ability, safe for plants, and low cost (Pansonato et al., 2011). Meanwhile, the use of phytoremediation treatment as a stand-alone unit process does not have the ability to reliably meet microbiological effluent standards (Arden and Ma, 2018; Li, Wichmann and Otterpohl, 2009). Therefore, it needs to be coupled with another effective and efficient pathogen treatment but there is currently a lack of performance analysis for a coupled greywater treatment plant in single houses under actual conditions. This study, therefore, aimed to evaluate the performance of a coupled greywater treatment and investigate the possibility of its implementation in the actual condition of a selected single house.

2 METHODS

The greywater treatment plant was installed in a single house with five inhabitants and its design was based on an assumption that 50-80% of water consumed is discharged as greywater while the detention time was derived from literature review. Moreover, the water consumption in the house was 40 m^3/month, therefore, the greywater production was 32 m^3/month and the detention time was designed not to be more than 1 to 2 days to avoid odor formation and the greywater turning blackish (Liu et al., 2010). The greywater stream was derived from the kitchen, washing machine, hand basin, and bathroom wastewater and the treatment units consist of sedimentation, filtration, phytoremediation, and disinfection chamber as shown in Figure 1. The treated greywater was used for garden watering and small fish pond while the overflow was discharged to the drainage channel. Furthermore, the flowrate, detention time, and the dimension of each unit of the greywater treatment plant are listed in Table 1 while the description for each treatment is presented in Table 2.

Table 1. The dimension of the combined greywater treatment

Volume (m^3)	Length (m)	Width (m)	Height (m)
Sedimentation Chamber – Compartment 1			
0.216	0.9	0.4	0.6
Sedimentation Chamber – Compartment 2			
0.21	0.9	0.35	0.69
Filtration Chamber			
0.1728	0.5	0.4	0.72
Phytoremediation Chamber			
0.828	2.3	0.6	0.6
Disinfection Chamber			
Bak 0.08	0.6	0.4	0.6

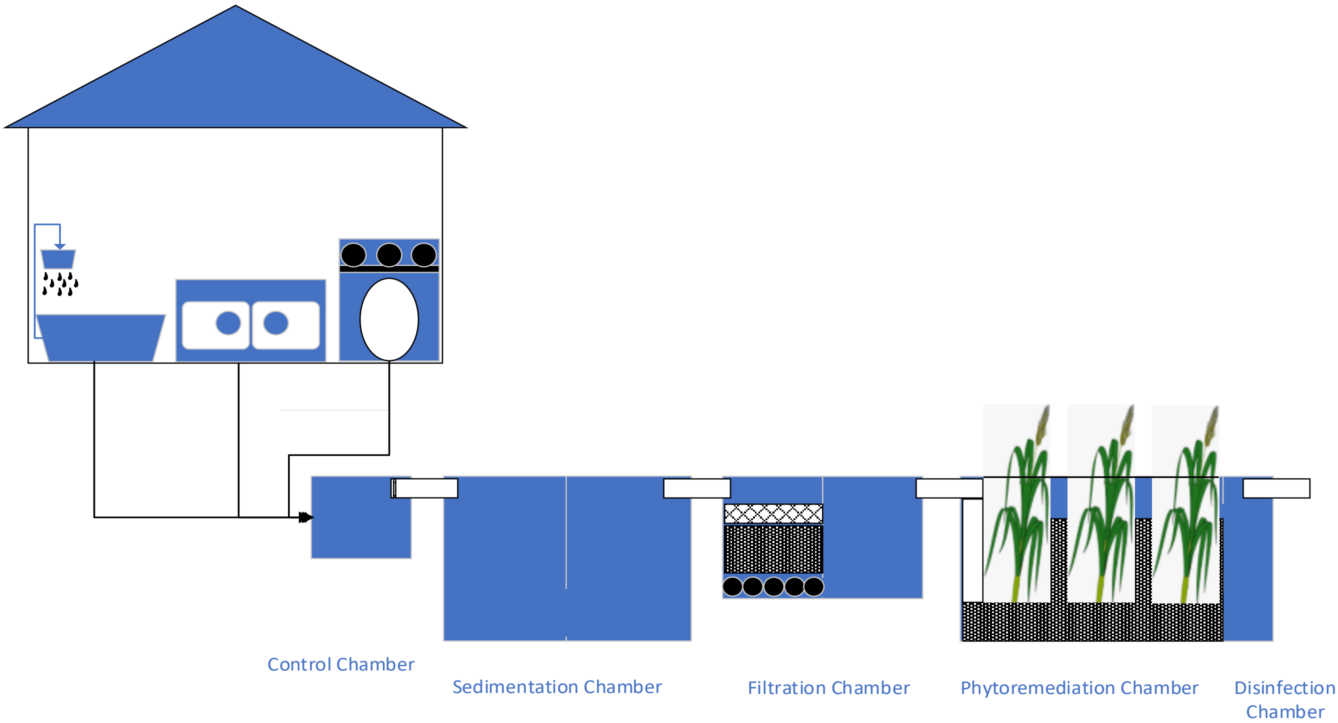

Figure 1. Scheme of the greywater treatment plant

Table 2. Description of the greywater treatment plant

Treatment Unit	Description	Component
Control Chamber	Greywater was discharged through the control chamber where a coarse sieve wire was installed to trap some trash in the greywater. The depth of the control box is 20 cm and has a square shape with a dimension of 30 cm × 30 cm.	Control chamber Cover Coarse sieve wire Inlet and outlet pipe
Sedimentation chamber	There are two compartments separated by a baffle in the chamber. The first compartment was intended to retain most of the solids and also to function as the grease and fat trap. The second compartment receives relatively clean greywater with fewer solids.	Two-compartment chamber. Cover Inlet and outlet pipe.
Filtration Chamber	Four filter media and a supporting medium were arranged in the filter, as described in the component column.	Filtration chamber Filter Media: first layer (cotton filter), the second layer (silica sand), the third layer (small gravel), fourth layer (zeolite) (Widiastuti et al., 2008) Supporting Medium: Gravel Inlet and outlet pipe
Phytoremediation Chamber	The inlet of the phytoremediation chamber was designed using perforated pipes to ensure the flow was distributed equally. This chamber has several plants with the ability to degrade organics. Four plantings were used in this study and arranged from the bottom as gravel, sand, soil, and garden gravel which were used for aesthetics. The greywater flows underneath the soil and plants in the form of horizontal sub-surface flow while the effluent was released to the disinfection chamber.	Phytoremediation chamber Gravel: Garden gravel Plants: Echinodorus palaefolius, Equisetum hyemale, Cyperus alternifolius, and Typha angustifolia L The perforated inlet pipe and outlet pipe
Disinfection chamber	This chamber was designed as an open and shallow chamber which allows the sunlight to penetrate to the deepest part. It was located in the section where it has maximum exposure to sunlight in order to ensure an effective solar disinfection process. Meanwhile, the overflow pipe was designed to be connected to the drainage channel.	Disinfection chamber Inlet pipe. Submersible pump and aerator Recycled water pipe Overflow pipe

The plants were selected based on their capabilities to remove organics and nutrients and also based on their aesthetics as shown in Figure 2 due to the intention to use them as garden plants. Previous studies have shown the ability of Echinodorus palaefolius, Equisetum hyemale, Cyperus alternifolius, and Typha angustifolia L to remove organics with the percentage listed in Table 3 (Kasman, Herawati, and Aryani, 2018; Suprihatin, 2014; Suswati and Wibisono, 2013; Wahyudianto et al., 2019)and also have the ability to remove some nutrients.

Echinodorus palaefolius — Equisetum hyemale — Cyperus alternifolius — Typha angustifolia L

Figure 2. Plants for phytoremediation.

Table 3. Efficiency removal of BOD and TSS for plants

Plants	Parameter	Removal	Reference	Detention Time
Echinodorus palaefolius	BOD TSS	43% 71%	(Kasman, Herawati and Aryani, 2018)	3 days
Equisetum hyemale	COD TSS Phosphate	53.57% 2.88% 95.49%	(Wahyudianto et al., 2019)	1 day
Cyperus alternifolius	BOD	97.9%	(Suprihatin, 2014)	1 day
Typha angustifolia L	BOD TSS TN T.P. F. Coliforms	92% 94% 45% 41% 99%	(Laaffat, Ouazzani and Mandi, 2015)	5.125 days

The water quality was analyzed with the focus on the parameters such as pH, BOD, TSS, Phosphate, and ammonia and each was analyzed in line with the procedure stipulated by the Indonesian National Standard (SNI) as shown in Table 4.

Table 4. Analysis method of greywater parameters

Parameter	Method	Indonesian National Standard Reference
BOD	Winkler	SNI 06.6989.72:2009
TSS	Gravimetric	SNI 06.6989.3:2004
Ammonia	Spektrofotometri	SNI 06.6989.30:2005
E.Coli	MPN	SNI 01.2332.1:2006

3 RESULTS AND DISCUSSIONS

3.1 Quantity of Greywater

The average flow over 14 days was observed to be 1,111 L/day and this corresponds to 222 L per capita per day while the daily average flow measured during the study period approached the design flow of 1,333 L/day. The daily flow was nearly similar to the values recorded in another research conducted in Malaysia with the freshwater consumption estimated at 226 L per capita per day (Oh et al., 2018). Moreover, a study conducted in 2015 reported the greywater flow in Indonesia to be approximately 60-178 l/c/d and this is much more similar to those produced in Vietnam which was estimated at 80-110 l/c/d (Firdayati et al., 2015) as shown in Table 5. The greywater flow in this study was much higher compared to the existing study in Bandung, Indonesia but it is important to note that its production depends more on water consumption. Meanwhile, a study reported water consumption to be different based on the geographical region (Hidayat et al., 2019) and those recorded in Tangerang, Depok, and Bogor found to be 159, 161.5, and 215.4 l/c/d respectively with Bogor which is located in highland and has a colder climate found to have relatively more water source. The inhabitants of Bogor consume more water compared to the other regions. Furthermore, Magelang is another region in highland with a colder climate and its inhabitants typically have high water consumption which was proved in this study by high greywater production.

Table 5. Comparison of greywater flowrate per person

Greywater Flowrate per person	Reference
222 l/c/d (Magelang)	This study
226 l/c/d (Malaysia)	(Oh et al., 2018)
60-178 l/c/d (Bandung) 80 – 110 l/c/d (Vietnam)	(Firdayati et al., 2015)

The greywater produced in high quantity is potentially used to replace water consumed indoor and outdoor after it has been appropriately treated to meet the water standard and the possible quantity of the water to be replaced using the treated greywater has been reported to be between 11,17% - 13,63% (Hidayat et al., 2019). A survey from Tangerang, Depok, and Bogor showed the respondents prefer to use treated greywater to water their garden but they were willing to increase the quantity as long as it has been appropriately treated. The use of treated greywater for other purposes has also been found to have the capability to save more water consumption. For example, it is used in the U.K. for toilet flushing, shower, baths, and laundry which constitute 68% of total potable water consumption (Liu et al., 2010).

3.2 Quality of Greywater

Significant amounts of organic matter, suspended solids, nitrogen compounds, and pathogens were recorded and compared with the domestic wastewater standard issued by the Provincial Regulation of Central Java No. 5 of 2012 and Indonesia Government Regulation No. 82 of 2001 (see Table 6) to determine the quality of influent and effluent of greywater treatment. The BOD/COD ratio in the influent was found to be 0,95 and this means the greywater contains more easily degradable organic material which is easily treatable using the biological treatment. Meanwhile, the concentration of wastewater effluent for many parameters was found to be below standards with only TSS observed to be higher than both standards. In contrast, BOD was discovered to be the only parameter which exceeded class 3 in Indonesia Government Regulation No. 82 of 2001, and the water in this class is only intended to be used for irrigation and fishery but only for a few fish such as catfish and tilapia. Moreover, ammonia was also one of the parameters which exceeded the standard regulation of the Province of Central Java and this means the combined treatment was unable to treat the nutrient content properly.

The greywater characteristics in this study were compared with other studies and the results are presented in Table 7. The significant organic matters, suspended solids, and ammonia were recorded in the influent and due to the derivation of greywater from the wastewaters from kitchen, bathroom, and laundry, the highest source of organic matter and ammonia most likely come from detergent while the TSS is from kitchen waste. Moreover, the pH was increasing during the treatment in a similar pattern with two of the studies presented in Table 7 and this is most probably due to the release of CO_2 from those taken by the plants or the supply of oxygen in the greywater. The table shows the greywater characteristics produced in the houses vary widely depending on the size and residents' habits (Fountoulakis et al., 2016).

Table 6. Quality comparison of treated greywater with the Indonesia Government Standard

Water Quality Parameters	Wastewater Influent (Inlet of Sedimentation Chamber)	Wastewater Effluent (Outlet of Disinfection Chamber)	Provincial Regulation of Central Java No. 5 of 2012	Indonesia Government Regulation No. 82 of 2001	Notes
Physical Parameter					
Temp. (°C)	27.3	26.7	30.0	Deviation 3.0	
TSS (mg/L)	252	128	100	50	
Chemical Parameter					
pH	7.34	7.62	6.00 – 9.00	6.00 – 9.00	
BOD_5 (mg/L)	219.5	18.2	50.0	6.0	
COD (mg/L)	232	40	100	50	
Ammonia (mg NH_4-N/L)	4.69	2.02	0.5	-	For fishery, free ammonia for sensitive fish <0,02 mg/L as NH_3
Iron (mg/L)	0.066	0.058	5.000	-	
Manganese (mg/L)	1.099	0.158	2.000	-	
Bacteriology Parameter					
E. Coli (MPN/100 mL)	≥2.400	280	5.000	2.000	

Table 8 shows the overall performance of the phytoremediation in this study and others which used phytoremediation and another method to treat greywater and the efficiency in removing organics was observed. The results showed E.coli decreased significantly particularly with the application of submerged membrane bioreactor (SMBR) but the reduction was lesser in the phytoremediation and plant treatment method at 18% to 99%. Meanwhile, the lesser removal of these pathogenic bacteria was associated with the ineffective treatment of plants in filtering the bacteria on its roots. The solar disinfection method was, however, observed to have the ability to assist in this condition but this depends on the depth of the disinfection chamber. Moreover, the removal of nutrients in the form of ammonia and heavy metals were also observed to be low due to the intention of the plant treatment to mostly remove organics rather than nutrients. Therefore, the phytoremediation or another plant treatment method was found to be ineffective in removing nutrient and pathogenic bacteria.

Further treatment is required to remove nutrient and pathogenic bacteria because the water produced from the phytoremediation process in this study does not fulfill the quality guidelines for toilet flushing in the U.K., Australia, and the USA (see Table 9). The treated greywater was observed to be more suitable for irrigation purposes due to the fact that the concentration for all the parameters is within the range allowed for irrigation and fishery for insensitive fish based on the Standard Regulation issued by the Indonesian Government Regulation No. 82 of 2001.

Table 7. Comparison of influent and effluent of greywater characteristics

Treatment / Parameter	Phytoremediation		Phytoremediation		Submerged Membrane Bioreactor		Phytoremediation		Constructed wetland		Constructed Wetland	
References	This Study		(Bute et al., 2017)		(Fountoulakis et al., 2016)		(Suprihatin, 2014)		(Laaffat, Ouazzani, and Mandi, 2015)		(Suswati and Wibisono, 2013)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	7.34	7.62	8.20	8.30	7.10	7.90	-	-	7.92	7.32		
TSS (mg/L)	252	128	32	16	95	8	-	-	4.9	0.29	255	9
BOD_5 (mg /L)	219.5	18.2	80	44	-	-	1632	34	44.2	3.45	104	0.33
COD (mg/L)	232	40	640	210	466	59			77.2	11.43	-	-
Ammonia (mg NH_4-N/L)	4.69	2	0.12	0.1	-	-	-	-	-	-	3.17	0.09
Iron (mg/L)	0.066	0.058	0.32	0.24	-	-	-	-	-	-	-	-
Manganese (mg/L)	1	0.158	-	-	-	-	-	-	-	-	-	-
E. Coli (MPN/100 mL)	≥2400	280	-	-	360000	<1	-	-	-	-	-	-
F. Coliforms (Log 10FC/100 ml)	-	-	-	-	-	-	-	-	5000	50	4.97	4.09

Table 8. Removal efficiency comparison for greywater treatment

Treatment	Phytoremediation	Phytoremediation	Submerged Membrane Bioreactor	Phytoremediation	Constructed wetland	Constructed Wetland
Source	This Study	(Bute et al., 2017)	(Fountoulakis et al., 2016)	(Suprihatin, 2014)	(Laaffat, Ouazzani and Mandi, 2015)	(Suswati and Wibisono, 2013)
pH	-	-	-	-	-	-
TSS (mg/L)	49%	50%	92%	-	94%	96%
BOD_5 (mg/L)	92%	45%	-	98%	92%	100%
COD (mg/L)	83%	67%	87%		85%	-
Ammonia (mg NH_4-N/L)	57%	17%	-	-	-	97%
Iron (mg/L)	12%	25%	-	-	-	-
Manganese (mg/L)	86%	-	-	-	-	-
E. Coli (MPN/100 mL)	88%	-	100%	-	-	-
F. Coliforms (Log 10FC/100 ml)	-	-	-	-	99%	18%

Table 9. Standard of toilet flushing compared to the results of this study

Parameter	This Study	The U.K.	Australia	USA
pH	7.62	5.00 – 9.50	6.50-8.50	-
BOD (mg/L)	18.2	-	<10	-
TSS (mg/L)	128	-	<10	-
E.coli (MPN/100 ml)	280	<25	<1	<100

5. CONCLUSION

A high volume of treated greywater in this study was found to be used as alternative water sources in households but the intake is very much dependent on the health and safety perception of the user. Moreover, greywater treatment technology is one of the factors considered to be important to the determination of the level of health and safety of the user. Therefore, this study evaluated the efficiency of a combined phytoremediation-solar disinfection treatment to reduce pollutants in greywater. The results showed the organic removal efficiency was 92% and 83% for BOD5 and COD respectively while the solids content had a smaller efficiency of 49% and ammonia concentration and pathogenic component was reduced by 57% and 88% respectively. The greywater produced in this single household contained a significant TSS, organic, nutrient, metal, and pathogenic bacteria and the combined phytoremediation-solar UV treatment was able to effectively treat the organics but had low removal efficiency for suspended solids, nutrients, metal, and pathogenic bacteria. Furthermore, the comparison of the results for the water quality standard for toilet flushing and water quality in this study showed the treated greywater did not fulfill the required standard but can be used for irrigation and fishery, particularly for insensitive fish such as catfish and tilapia. This research showed the treatment technique using plants and solar UV treatment is not yet able to provide treated water to replace the water consumption within the household despite the high flowrate of greywater. Therefore, a more advanced treatment method such as Submerged Membrane Bioreactor is recommended to be applied in order to maximize the intake of treated greywater for indoor and outdoor uses.

DISCLAIMER

The authors declare no conflict of interest.

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