Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.23631

146 (2019) 141–151
April

Design of a compact and effective greywater treatment system in Malaysia

Zhi Chao Ong[a,*], Mohammadjavad Asadsangabifard[b], Zubaidah Ismail[b],
Jun Hui Tam[a], Peiman Roushenas[a]

[a]*Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia, Tel. (+603) 7967 6815; Fax: +603 79675317; emails: alexongzc@um.edu.my (Z.C. Ong), junhui@siswa.um.edu.my (J.H. Tam), roushenaspeiman@gmail.com (P. Roushenas)*
[b]*Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia, emails: asfardmj@gmail.com (M. Asadsangabifard), zu_ismail@um.edu.my (Z. Ismail)*

Received 7 June 2018; Accepted 9 December 2018

ABSTRACT

Water shortage has been one of the major concerns faced by about 2.7 billion people around the world due to several factors, including water pollution, climatic change, etc. Several nations have been seeking practical alternatives to address this issue and one of the most pragmatic approaches is the development and implementation of greywater treatment systems. To date, a great assortment of greywater treatment systems have been developed. The current study presents a different water treatment system to treat residential, commercial and industrial greywater in Malaysia. Unlike most existing systems which involve separate steps of treatment, the proposed method integrates aeration, disinfection and membrane filtration in a compact reactor, which could potentially reduce the operational cost, space and equipment. Aeration is required to promote pollutant degradation by aerobic microorganisms, while disinfection (UV) is needed to eliminate pathogenic bacteria. Subsequently, membrane filtration is used to remove suspended and dissolved pollutants of which are relatively smaller in size. The results have proven that the proposed system is effective in improving the quality of greywater, in which, the parameters (BOD, turbidity, total suspended solids, TDS, pH, DO) are reported to be in good agreement with the standards. While this study is conducted in a laboratory environment, its excellent results suggest that the proposed system is potentially practical for commercial use in future.

Keywords: Aeration; Disinfection; Greywater; Malaysia; Membrane filtration

1. Introduction

In accordance with the vision of becoming a developed country by 2020, Malaysia has undergone rapid development in various aspects, including industrialization, urbanization, tourism and communications [1]. As a result of the progressive development, the amount of wastewater discharged from industrial and domestic sources into water channels is increasing, thereby, leading to water pollution. Consequently, water crisis is triggered, constricting the accessibility of freshwater supplies. Due to the severity of these issues, authorities have been investing much time and effort in investigating and treating domestic wastewater. Domestic wastewater can be categorized into black water, brown water, yellow water, greywater, and white water [2]. According to Fountoulakis et al. [3], greywater, which is a source of wastewater generated from kitchen sinks, bathroom sinks, showers and/or baths, and laundry, composes 50%–70% of the total domestic wastewater. Given its relatively low organic pollutant content (30%) and low nutrient content (9%–20%), greywater has been the primary alternative water source, in which, the treatment is relatively easy and the source is relatively abundant as compared with the others [4].

* Corresponding author.

Greywater is generated on a day-to-day basis at different amounts in a household. The highest amount of greywater being discharged daily is recorded to be before and after normal working hours. The composition variation of greywater depends substantially on the type of chemicals used (detergents, soaps, toothpastes, etc.), gender, water availability, age, household occupancy, country, etc. The ratio of the chemical oxygen demand to biological oxygen demand (COD:BOD) can reach at most by 4:1, implying that the greywater contains higher chemical and heavy metal contents [5]. On the contrary, the presence of nutrients P and N and pathogens are normally insignificant. Surfactants and detergents constitute the most in greywater composition. These constituents are toxic and detrimental to plants and aquatic animals at certain concentrations. Household washing softeners and detergents are harmful to marine animals at concentrations around 0.07–35.4 mg L^{-1}, while non-ionic surfactants, anionic surfactants, boron and phosphate are harmful to aquatic organisms at concentrations around 0.3–200 mg/L, 0.0025–300 mg/L, 4.6–226 mg/L, and 5–9 mg/L, respectively [6].

The reuse of greywater without treatment is prevalent, for example, garden watering [7,8], landscape irrigation [9], etc. The amount of nutrients varies in the composition of greywater and the presence of micronutrients (Zn, Mn, and Cu) as well as macronutrients (N, S, P, Ca, K, and Mg) can be useful to plants [10], for example, tomatoes [11], silver beets [12], residential lawns, etc. Nevertheless, the treatment of greywater before reuse is strongly recommended to minimize the possibility of harming the environment or living organisms. There are several types or stages of treatment, including biological, physical, chemical, or/and disinfection. The treatment of raw greywater usually begins with a screening process and proceeds with sedimentation to eliminate suspended solids and coarse particles. The pre-treated greywater is then channelled into the main treatment plants comprising biological, physical, chemical or/and extensive treatment units before the final disinfection process takes place.

Several types of biological systems have been developed and adopted to treat greywater, such as the membrane bioreactor (MBR) [13–15], upflow anaerobic sludge blanket (UASB) [16], biological aerated filter [17], fluidized bed reactor [18], rotating biological contractor (RBC) [19], sequencing batch reactor (SBR) [20], and submerged membrane bioreactor [21]. Biological systems are normally implemented before a coarse filtration stage as well as after a sedimentation/filtration stage to remove biosolids or sludge. Besides, biological treatment can also be categorized into anaerobic and aerobic treatments. Anaerobic treatment of greywater has been studied employing the UASB [16] and a conventional anaerobic reactor [22]. Anaerobic treatment can be slow and inefficient in achieving a sufficient methanogenic activity which is the last and important stage of pollutant biodegradation [23]. However, anaerobic treatment can be best utilized as a pre-treatment as well as coupled with aerobic treatment, provided that proper insulation and disinfection are performed. As compared with anaerobic treatment, aerobic treatment is relatively better in removing the toxic effects contained in greywater [24].

Physical systems involve filtration and sedimentation. Filtration is normally adopted as a pre-treatment process before proceeding to biological and chemical treatments. Filtration is required to reduce or eliminate suspended solids before proceeding to further treatment. It should be informed that solid particles may induce the formation of pathogens from disinfectants (UV, chlorine), while organic particles may favour the formation of disinfectant by-products (chloramines, trihalomethanes), and thereby, aggravating the activity of disinfection. The typical examples of filtration used as a pre-treatment include metal strainers [25], screen meshes [26], sand bed filtration [27], gravel filtration [26], nylon-sock type filtration [28], and mulch tower system [29]. Generally, physical systems are less efficient in eliminating organic particles, nutrients and pathogens as they are mainly utilized in pre-treatment stages as well as in less stringent applications, where the water quality is of less emphasis.

Chemical systems include coagulation [30], electrocoagulation [31,32], magnetic ion exchange resin [33], powdered activated carbon and advanced oxidation processes [34], adsorption using granular activated carbon (GAC) [30], natural zeolites [35], photocatalysis [36], and ultraviolet C (UVC)/H_2O_2 [37]. Chemical systems are efficient in treating greywater as a final treatment step, following the biological treatment. It is notable that disinfection is not needed when performing photocatalysis since the photocatalytic degradation of pathogens takes place in the presence of UV light.

Comparing with other developed countries, the implementation of greywater treatment systems is relatively less common in Malaysia on account of the limited resources and knowledge in executing and sustaining the systems. In Malaysia, greywater is usually treated together with black water in a centralized treatment facility [38]. This centralized treatment system in Malaysia comprises four main stages [39]. The wastewater will initially undergo pre-treatment to eliminate coarse substances before entering the primary treatment unit. The effluent will subsequently be transferred from the primary treatment unit to the secondary treatment unit, such as SBRs, activated sludge systems, RBCs and contact stabilization before releasing into the water channels. Nevertheless, complexity in the treatment processes, high operational cost as well as high sensitivity with respect to changes in the environment are the main concerns. The last treatment step, disinfection is needed to get rid of both the pathogens and odours from the treated greywater to preserve its hygiene and cleanliness. A few studies have been conducted in investigating and implementing greywater treatment systems in Malaysia. Mah et al. [38] presented the conceptual modelling of a greywater treatment system, in which a pilot project, Ecological Sanitation (Ecosan) was proposed and its mathematical model was developed through simulation in Kuching, Sarawak in 2003. The objective of the treatment system is to treat greywater generated from the showers, washing machines and kitchen, while the aim of this project is to minimize pollution caused by the discharge of untreated greywater into water streams. In this regard, the Ecosan project adopted the application of wetlands with integrated aerobic filter for greywater treatment. Consequently, the pollutant content released into the water channels was reduced. This treated greywater is suitable for non-drinkable reuse and a predicted average reduction of 40% of potable water consumption could be achieved. Furthermore, Oh et al. [40] proposed a greywater recycling system installed at Monash University Malaysia. The recycling system is composed of a sand filter, an activated carbon filter and an ozone disinfection unit. To achieve the tip-top disinfection efficiency which subsequently producing treated greywater that complies with the standard requirements, the ozone dosage of the system was optimized. Importantly, this system has been proven capable of saving fresh water or potable water, which could cater for 140 persons or 28 families with an average of 5 family members. Apart from that, Radin Mohamed et al. [41] developed and installed an ablution greywater recycling system in two mosques located at Batu Pahat, Johor. Ablution greywater has low pollutant content and it is usually treated using a simple sand-gravel filter. The treated greywater is applicable for toilet flushing or garden watering. Leong et al. [42] proposed a decentralized hybrid rainwater–greywater system operating on a pilot-scale under controlled conditions in Malaysia. The system featured a multimedia filter, a GAC filter, and ozone disinfection. In summary, the system successfully treated greywater generated from a mixture of showers/baths and laundry with reduction of 52% COD, 53% BOD_5, 81% turbidity, 50% total suspended solids (TSS), 14% NH_3-N, 67% PO_4-P, 81% colour, 53% of total coliforms, 63% copper (Cu), and 29% zinc (Zn).

The aforementioned literature demonstrates that the implementation of greywater systems in Malaysia is still in its infancy due to various factors, such as limited resources as well as lack of knowledge and awareness. As reviewed, pilot-scale greywater treatment systems have been proposed and studied in Malaysia involving separate treatment steps, namely, primary filtration, secondary filtration, and ozone disinfection. Technically, this might incur more operational cost, space, and equipment. Ozone disinfection is known to be relatively more effective compared with UV disinfection as ozone disinfection will permanently eradicate bacteria and microorganisms. However, from the viewpoint of accessibility and cost, UV disinfection is relatively more advantageous compared with ozone disinfection. Therefore, the present paper proposes a greywater treatment system, which combines the three main treatment steps, namely, aeration, UV disinfection, and filtration, in a compact reactor to treat residential, commercial and industrial greywater in Malaysia. In this regard, residential greywater is referred to the water generated from residential household, for example, bathing, toilet flushing, laundry, dishwashing, etc. On the contrary, commercial and industrial greywater is referred to the water discharged from commercial and industrial premises, such as restaurants, offices, hotels, factories, etc.

2. Materials and methods

2.1. Greywater treatment design

While a number of greywater treatment methods are available, the type of treatment required is largely determined by the following variables: the quality of the incoming greywater, the planned end use, and the degree of care and intervention desired by the user. The proposed greywater treatment system consists of a bag and cartridge filter, a compact reactor (main tank) and several pumps, as shown in Fig. 1. Generally, it comprises two main stages, in which, stage 1 involves the bag and cartridge filtration, and stage 2 involves the treatment of the compact reactor. The compact reactor is composed of a membrane filter, UV lamps, and aeration bubble diffusers, as demonstrated in Figs. 2 and 3. The reactor is supported by the bag and cartridge filter to prevent or reduce the entry of suspended particles into the tank. Greywater initially flows into the bag and cartridge filter before entering the main tank. The treatment tank is designed such that the flow of greywater is guided from the edges to the centre of the tank, as depicted in Fig. 3. A square spiral liquid flow way is designed in the main tank, where, UV lamps are placed at the corners along the flow way and aeration bubble diffusers are located at the bottom of the main tank along the flow way. The primary objective of this spiral-shaped design is to optimize the rate of aeration and disinfection of greywater before undergoing membrane filtration. As the greywater enters the tank, microbial degradation and disinfection (UV lamps) will occur concurrently and eventually, membrane filtration will take place. Aeration is needed to increase the level of dissolved oxygen in the greywater, which will promote aerobic microbial growth and thereby inciting the degradation of organic pollutants. Disinfection is needed to eliminate pathogenic bacteria, while membrane filtration is needed to further remove suspended and dissolved pollutants. The specifications of the materials

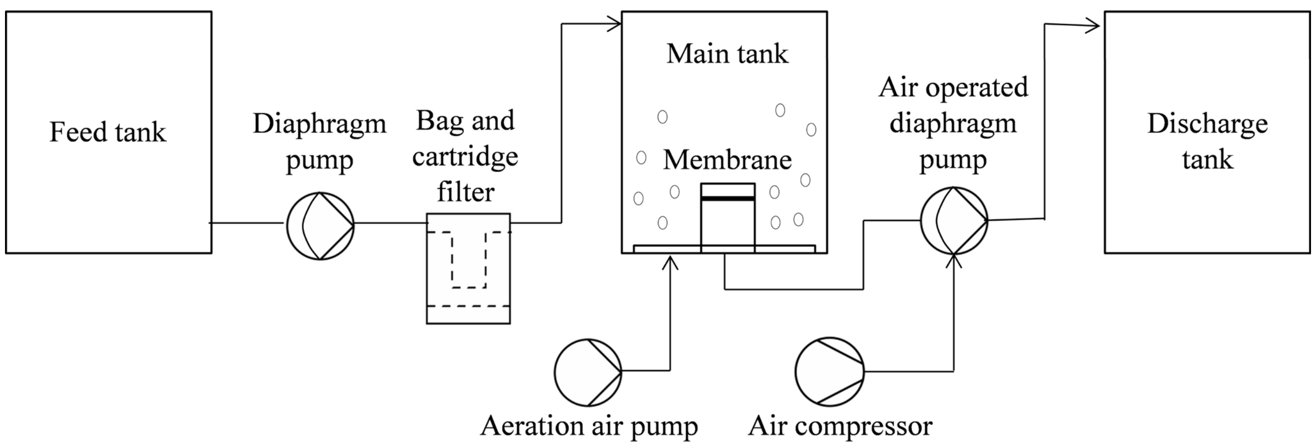

Fig. 1. Schematic diagram of the proposed greywater treatment system.

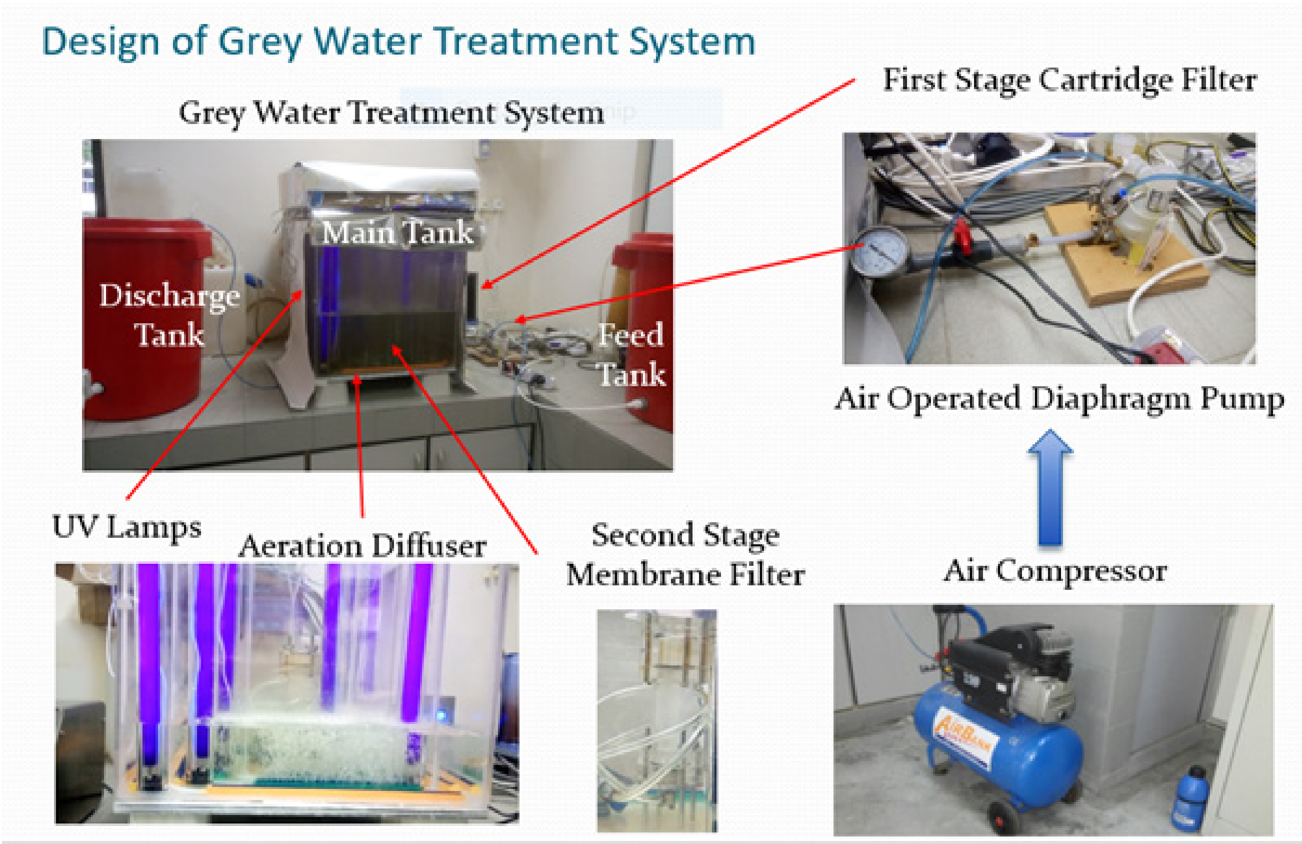

Fig. 2. Proposed greywater treatment system.

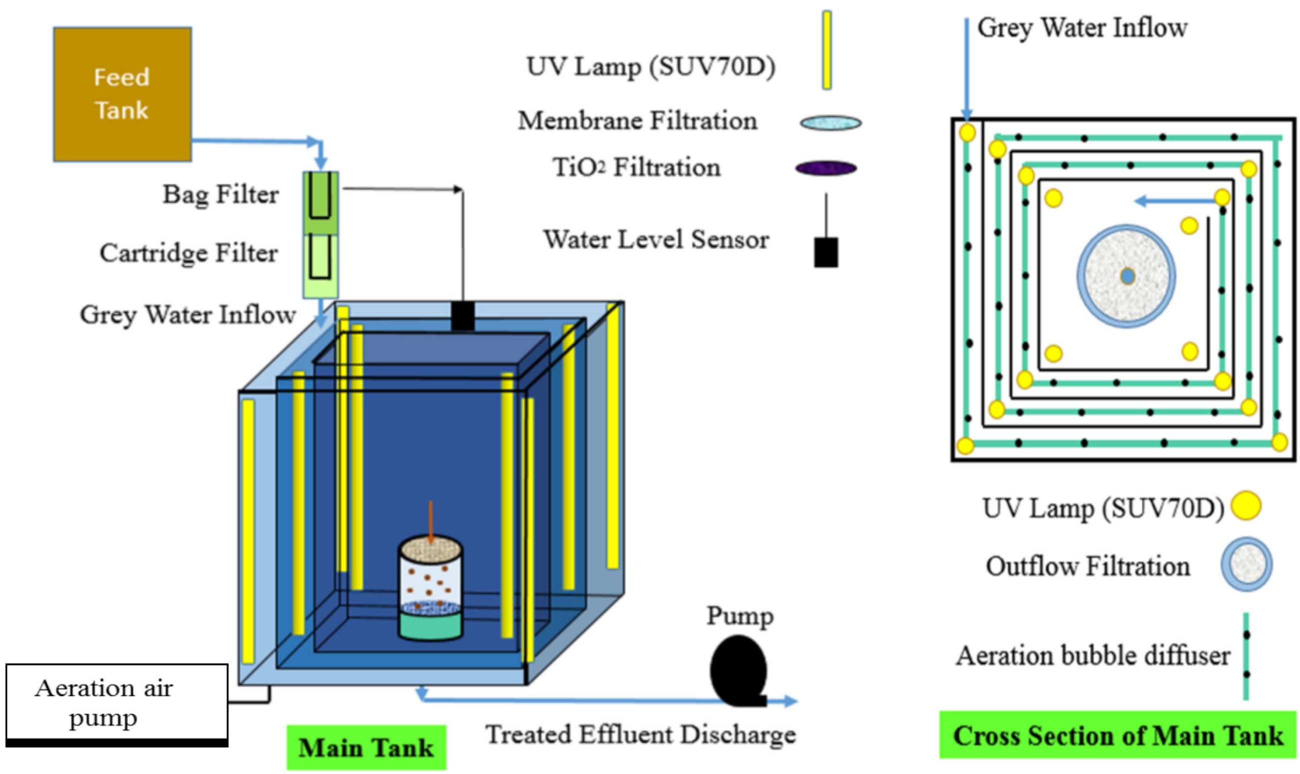

Fig. 3. Details of the compact reactor (main tank).

and equipment involved in operating the proposed system are listed in Table 1. The performances of the system are subsequently investigated on the basis of the treated greywater quality by varying the conditions used, the configuration, and operating parameters. Based on the results, the variables of the system are optimized to achieve tip top system efficiency as well as to meet the standard requirements.

2.2. Water sampling

The Penchala River is one of the main rivers in Klang basin and it flows across urban areas where diverse land use is established. According to the recent water quality data, the Penchala River has been experiencing severe pollution with the water quality index (WQI) ranging from III to V since the catchment areas of which are mostly located at urban areas, where residential, commercial and industrial activities are prevalent. In this study, spatial and temporal sampling methods were adopted. In the present context, spatial sampling refers to the collection of samples at different locations, while temporal sampling refers to the collection of samples at different time. In terms of spatial sampling, three sampling sites were selected, as shown in Fig. 4. The exact locations of the sites are listed in Table 2. It is notable that S1 and S3 are located at residential areas, while S2 is located at commercial and industrial areas. The details of the surrounding areas of each sampling sites are presented in the Appendix.

Table 1
Specifications of materials and equipment

Main tank	Dimension: 50 × 50 × 50 cm^3
Bag and cartridge filter	AMGO 5 μm polypropylene fibre
UV lamps	SUV70D 50W 0.8A UV wavelength: 254 nm UV irradiance at 1 m: 150 $\mu W/cm^2$
Membrane	11104 Cellulose acetate 0.8 μm 120 mm thickness
Influent pump	Dauer HF-8367 DC 24V 125Psi (0.862 MPa) 1.2 L/min
Aeration air pump	Atman HP-4000 AC 220-240 V/50 Hz 20 W 0.022 MPa 35 L/min
Air operated diaphragm pump	Wilden P.025 Plastic PTFE-Fitted Discharge pressure: 4 Bar (0.4 MPa)
Air compressor	LW-2501 2.5 HP 2kW 116 Psi (0.800 MPa) 120 L/min
YSI ProDSS multi-parameter water quality meter	Dissolved oxygen (DO), turbidity, pH, total dissolved solids (TDS), total suspended solids (TSS)

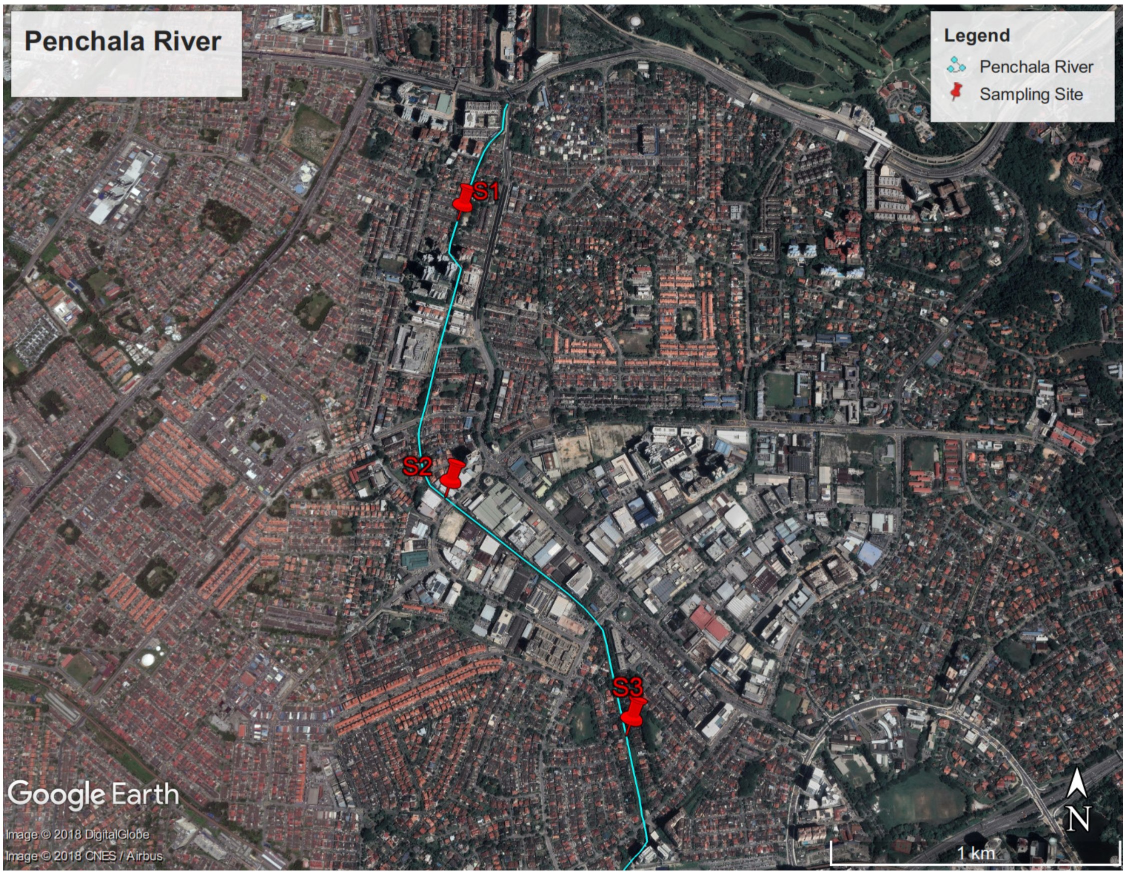

Fig. 4. Sampling site along the Penchala River.

Table 2
Location of the sampling location

Sampling site	Location	Latitude	Longitude
S1	Jalan 19/21	3°7′33.22″N	101°37′41.77″E
S2	Jalan 19/1	3°6′57.95″N	101°37′41.28″E
S3	Jalan 14/30	3°6′30.63″N	101°38′2.70″E

In terms of temporal sampling, samples were collected at different time (morning, afternoon, and night). In this study, a total of 45 samples were collected at three sampling sites, in which, a total of 5 sampling days were needed for all the sites and 3 samples were collected each day at each site. Samples were collected from the drainage outlet and sent to laboratory for analyses. The sampling was done exactly at the point of discharge before flowing into the river. The water quality parameters of the samples (DO, turbidity, pH, TDS, and TSS) were measured in-situ using the YSI ProDSS multi-parameter water quality meter. Biochemical oxygen demand (BOD_5) was calculated by quantifying the dissolved oxygen of the sample before and after the 5-day incubation at 20°C.

3. Results and discussion

The proposed greywater treatment system comprises two main stages, in which, stage 1 involves the bag and cartridge filtration, and stage 2 involves the integration of aeration, disinfection, and membrane filtration. Table 3 demonstrates the turbidity, TSS, TDS, BOD, DO, and pH of greywater before and after treatment. Basically, BOD refers to the amount of dissolved oxygen needed by aerobic microorganisms to decompose organic pollutants. The BOD reduction percentages of greywater before and after stage 1 range from 8.09% to 29.41%. After stage 2, the BOD of treated greywater is further reduced by at least 7.14%, up to 58.82%. This occurrence literally signifies that aeration plays a pivotal role in promoting biodegradation of organic pollutant by aerobic microorganism and thereby reducing the BOD by supplying a sufficient amount of dissolved oxygen [43]. In the case of S2, the relatively low removal percentage of BOD (37.14%) suggests that the presence of inorganic pollutants is relatively more significant than that of organic pollutants due to the discharge of commercial and industrial wastes. Inorganic pollutants include all those that do not contain a carbon-to-carbon or carbon-to-hydrogen bond [44]. Metals, metalloids, and their compounds are the examples of inorganic pollutants, which are mostly found in commercial and industrial wastes. The typical inorganic pollutants released from commercial and industrial activities are ammonia (food industry), arsenic (metal industry), chromium (dye industry), etc. Notably, aerobic bacteria are responsible in decomposing organic pollutants in the presence of dissolved oxygen. Due to the relatively higher concentration of inorganic pollutants in industrial wastes, the growth as well as the activity of aerobic microorganisms in organic pollutant degradation are impeded and hence, limiting the reduction percentage of BOD. An inverse relationship exists between DO and BOD, in which, at the end of the treatment, the DO of treated greywater is reported to be higher than those before treatment.

Table 3
Greywater quality before and after treatment

Parameters	Turbidity (NTU)	*R* (%)	TSS (mg/L)	*R* (%)	TDS (mg/L)	*R* (%)	BOD (mg/L)	*R* (%)	DO (mg/L)	*A* (%)	pH	*A* (%)
S1												
Untreated	159.46	NA	258	NA	346	NA	13.6	NA	1.26	NA	7.52	NA
Stage 1 (5 µm)	22.96	85.60	42	83.72	315	8.96	12.5	8.09	6.06	380.95	7.93	5.45
Stage 2 (0.8 µm)	9.55	94.01	15	94.19	305	11.85	7.3	46.32	8.61	583.33	8.52	13.30
S2												
Untreated	23.27	NA	38	NA	203	NA	8.75	NA	0.26	NA	5.72	NA
Stage 1 (5 µm)	10.12	56.51	16	57.89	199	1.97	7	20.00	0.86	230.77	5.98	4.55
Stage 2 (0.8 µm)	9.55	58.96	15	60.53	180	11.33	5.5	37.14	8.61	3,211.54	8.52	48.95
S3												
Untreated	23.4	NA	38	NA	162	NA	3.4	NA	73.5	NA	6.87	NA
Stage 1 (5 µm)	12.3	47.44	20	47.37	159	1.85	2.4	29.41	105.1	42.99	7.33	6.70
Stage 2 (0.8 µm)	4.6	80.34	7	81.58	154	4.94	1.4	58.82	111.3	51.43	7.79	13.39

NA: not available; *A*: addition percentage; *R*: reduction percentage.

As seen from the table, the removal percentage of turbidity and TSS after stages 1 and 2 are almost similar. Physical processes, namely, coarse filtration and membrane filtration, contribute the most in removing TSS and turbidity, in which coarse filtration is usually used for pre-treatment, while membrane filtration is typically used for post-treatment [45,46]. According to Hannouche et al. [47], a strong linear relationship exists between turbidity and TSS concentration. Turbidity is an optical determination of water clarity and it is determined based on the amount of light scattered by particles in the water. Turbidity can be used to estimate the TSS concentration, but it will be less accurate since turbidity does not take into account settled solids or bed load (sediment that flows along the riverbed). In addition, coloured dissolved organic matter, fluorescent dissolved organic matter and dyes can as well affect the turbidity of water [48]. On the contrary, total suspended solids (TSS) are particles of larger sizes that are found in the water and they are determined based on the total quantity measurement of solid material per volume of water, including suspended organic and inorganic matters as well as settled solids. In this regard, dissolved organic and inorganic matters are not considered as part of the TSS.

It can be observed that the greywater obtained from S1 is slightly more alkaline; S1 is located at high-density residential areas, in which the sources of greywater can be originated from bathing, toilet flushing, laundry, dishwashing, etc. Since soaps, detergents, and dishwashers are generally known to be alkaline, the discharged wastes are thus reported to have relatively higher pH. Majority of the soaps have a pH within the range of 9–10 [49]. The slightly more acidic greywater sampled at S2 with pH of 5.72 indicates that the wastes produced by the nearby commercial premises and industrial factories can be relatively rich in heavy metals and other inorganic pollutants, which are known to be the sources of acidity. In addition, the pH of greywater taken from S3, which is located at residential areas, is approaching neutral. Referring to all the parameters before treatment, it can be deduced that the concentration of pollutants in greywater obtained from S3 is relatively lower than those from S1 and S2.

According to Oh et al. [50], Malaysia does not have water quality standards for treated greywater, hence urban reuse guidelines are proposed on the basis of those implemented by other countries, that is, USA, UK, Canada, Italy, Australia, New South Wales, and Israel. As stated, the BOD of treated greywater should not exceed 20 mg/L, while treated greywater turbidity should not exceed 10 NTU. In most cases, the TSS value of treated greywater should be maintained below 30 mg/L. In addition, the allowable pH for treated greywater should be recorded within the range of 5.0–9.5. The BOD of treated greywater, obtained from all the sampling sites, falls within the standard allowable range (<20 mg/L), as demonstrated in Fig. 5. This indication suggests that aeration is imperative in promoting pollutant degradation by aerobic microorganism and thereby reducing the BOD. Furthermore, the turbidity of treated greywater, obtained from all the sites, does not exceed the maximum standard limit (<10 NTU), as depicted in Fig. 6. As seen from Fig. 7, the TSS of treated greywater, taken from all the sites, does comply with the standard (<30 mg/L) as well. These outcomes directly validate the effectiveness of the membrane filtration in the proposed system. Besides, the treated greywater is reported to be slightly alkaline, in which, the pH falls within the standard range (5.0 < pH < 9.5), as demonstrated in Fig. 8.

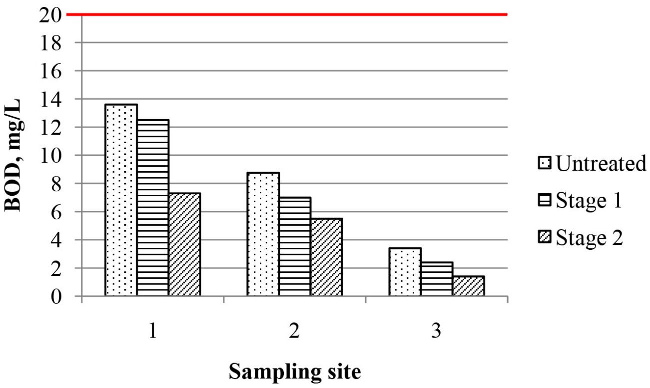

Fig. 5. Biochemical oxygen demand (BOD) of greywater before and after treatment. Red horizontal line indicates the maximum standard limit of BOD.

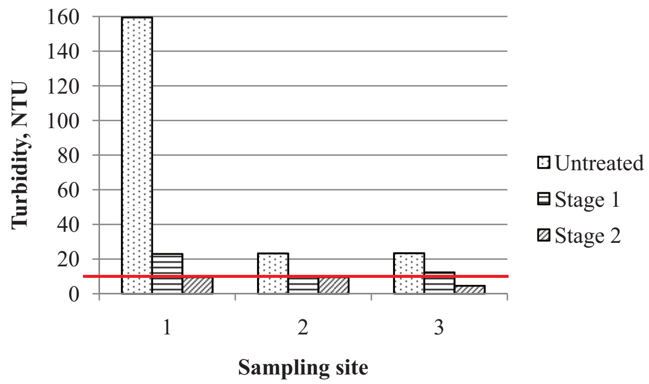

Fig. 6. Turbidity of greywater before and after treatment. Red horizontal line indicates the maximum standard limit of turbidity.

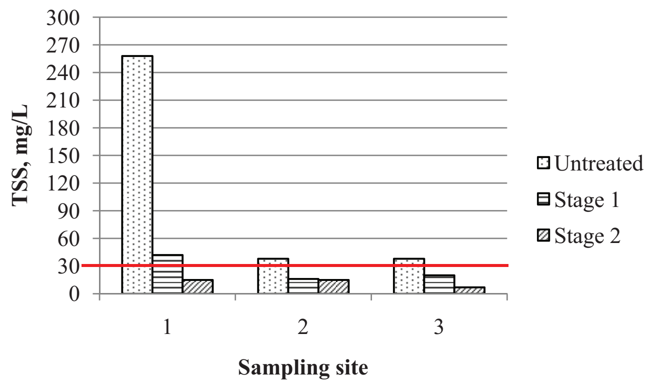

Fig. 7. Total suspended solids (TSS) of greywater before and after treatment. Red horizontal line indicates the maximum standard limit of TSS.

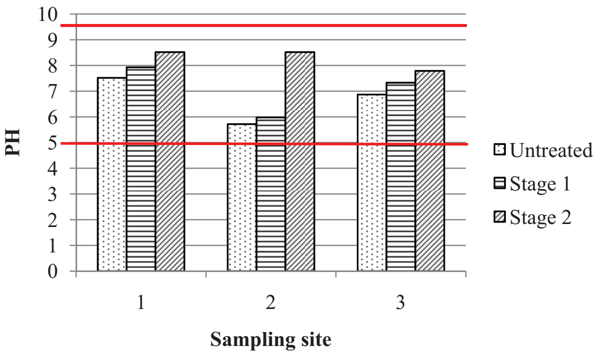

Fig. 8. pH of greywater before and after treatment. Red horizontal lines indicate the standard range of pH.

4. Conclusion

A new different greywater treatment system has been designed to treat residential, commercial, and industrial greywater in Malaysia. In the present paper, the technical design and efficiency of the system are the emphasis. The salient feature of the proposed system consists in the integration of aeration, disinfection, and membrane filtration in a compact reactor, unlike those existing systems that involve separate treatment stages. Aeration is performed to promote degradation of organic pollutants by aerobic microorganisms and in the meantime, disinfection is carried out in the presence of UV rays to get rid of pathogenic bacteria. Finally, membrane filtration is used to further eliminate suspended and dissolved pollutants. By combining these three processes, the operational cost, space as well as equipment can be reduced considerably. The results have proven that the proposed system is able to treat greywater (BOD, turbidity, TSS, TDS, pH, and DO) effectively under the condition that maintenance (e.g., cleaning of filters) should be performed regularly to avoid performance deterioration. It is notable that the present research involves an elementary laboratory-scale study of a new greywater treatment system, which is worth to be investigated and applied commercially in future. The incorporation of titanium dioxide into the proposed system to expedite the treatment processes can be a plausible solution due to its excellent photocatalytic activity which promotes photodegradation of organic pollutants.

Acknowledgement

The authors would like to acknowledge the financial support and advice given by Postgraduate Research Fund (PG009-2015A); University Malaya Research Grant (RP013B-15SUS); Advanced Shock and Vibration Research (ASVR) Group of University of Malaya; and other project collaborators.

Author contributions

This study was initiated by Zhi Chao Ong, Mohammadjavad Asadsangabifard and Zubaidah Ismail. Zhi Chao Ong and Zubaidah Ismail provided in-depth comments and advices throughout the research. Mohammadjavad Asadsangabifard and Peiman Roushenas conducted site sampling and water quality tests. Jun Hui Tam contributed in writing and revising the paper.

References

[1] N.W. Chan, Water resources management in Malaysia: NGO. In: Perspectives Paper Presented during MENGO's Sustainable Development Conference PWTC, Kuala Lumpur, Malaysia, 2005, p. 9.
[2] N. Gray, Drinking water quality: problems and solutions. Chichester: John Wiley & Sons, 1994. p. 132–148.
[3] M.S. Fountoulakis, N. Markakis, I. Petousi, T. Manios, Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing, Sci. Total Environ., 551 (2016) 706–711.
[4] D.M. Revitt, E. Eriksson, E. Donner, The implications of household greywater treatment and reuse for municipal wastewater flows and micropollutant loads, Water Res., 45 (2011) 1549–1560.
[5] B. Jefferson, A. Laine, S. Parsons, T. Stephenson, S. Judd, Technologies for domestic wastewater recycling, Urban Water, 1 (2000) 285–292.
[6] A. Pettersson, M. Adamsson, G. Dave, Toxicity and detoxification of Swedish detergents and softener products, Chemosphere, 41 (2000) 1611–1620.
[7] S.S. Dalahmeh, M. Assayed, W.T. Suleiman, Themes of stakeholder participation in greywater management in rural communities in Jordan, Desalination, 243 (2009) 159–169.
[8] A.M. Ryan, C.L. Spash, T.G. Measham, Socio-economic and psychological predictors of domestic greywater and rainwater collection: evidence from Australia, J. Hydrol., 379 (2009) 164–171.
[9] Z. Ronen, A. Guerrero, A. Gross, Greywater disinfection with the environmentally friendly hydrogen peroxide plus (HPP), Chemosphere, 78 (2010) 61–65.
[10] N. Rodda, L. Salukazana, S.A.F. Jackson, M.T. Smith, Use of domestic greywater for small-scale irrigation of food crops: effects on plants and soil, Phys. Chem. Earth, 36 (2011) 1051–1062.
[11] R.K. Misra, J.H. Patel, V.R. Baxi, Reuse potential of laundry greywater for irrigation based on growth, water and nutrient use of tomato, J. Hydrol., 386 (2010) 95–102.
[12] U. Pinto, B.L. Maheshwari, H.S. Grewal, Effects of greywater irrigation on plant growth, water use and soil properties, Resour. Conserv. Recycl., 54 (2010) 429–435.
[13] A. Huelgas, N. Funamizu, Flat-plate submerged membrane bioreactor for the treatment of higher-load graywater, Desalination, 250 (2010) 162–166.
[14] K. Bani-Melhem, Z. Al-Qodah, M. Al-Shannag, A. Qasaimeh, M. Rasool Qtaishat, M. Alkasrawi, On the performance of real grey water treatment using a submerged membrane bioreactor system, J. Membr. Sci., 476 (2015) 40–49.
[15] E. Smith, K. Bani-Melhem, Grey water characterization and treatment for reuse in an arid environment, Water Sci. Technol., 66 (2012) 72–78.
[16] T.A. Elmitwalli, R. Otterpohl, Anaerobic biodegradability and treatment of grey water in upflow anaerobic sludge blanket (UASB) reactor, Water Res., 41 (2007) 1379–1387.
[17] B. Lodge, S.J. Judd, A.J. Smith, Characterisation of dead-end ultrafiltration of biotreated domestic wastewater, J. Membr. Sci., 231 (2004) 91–98.
[18] E. Nolde, Greywater reuse systems for toilet flushing in multi-storey buildings – over ten years experience in Berlin, Urban Water, 1 (2000) 275–284.
[19] E. Friedler, R. Kovalio, N.I. Galil, On-site greywater treatment and reuse in multi-storey buildings, Water Sci. Technol., 51 (2005) 187–194.
[20] M. Kraume, R. Scheumann, A. Baban, B. El Hamouri, Performance of a compact submerged membrane sequencing batch reactor (SM-SBR) for greywater treatment, Desalination, 250 (2010) 1011–1013.
[21] K. Bani-Melhem, E. Smith, Grey water treatment by a continuous process of an electrocoagulation unit and a submerged membrane bioreactor system, Chem. Eng. J., 198–199 (2012) 201–210.

[22] L. Hernández Leal, G. Zeeman, H. Temmink, C. Buisman, Characterisation and biological treatment of greywater, Water Sci. Technol., 56 (2007) 193–200.

[23] L. Abu Ghunmi, G. Zeeman, M. Fayyad, J.B. van Lier, Grey water treatment in a series anaerobic - Aerobic system for irrigation, Bioresour. Technol., 101 (2010) 41–50.

[24] L.H. Leal, A.M. Soeter, S.A.E. Kools, M.H.S. Kraak, J.R. Parsons, H. Temmink, G. Zeeman, C.J.N. Buisman, Ecotoxicological assessment of grey water treatment systems with *Daphnia magna* and *Chironomus riparius*, Water Res., 46 (2012) 1038–1044.

[25] O.R. Al-Jayyousi, Greywater reuse: towards sustainable water management, Desalination, 156 (2003) 181–192.

[26] D. Mandal, P. Labhasetwar, S. Dhone, A.S. Dubey, G. Shinde, S. Wate, Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries, Resour. Conserv. Recycl., 55 (2011) 356–361.

[27] K. Chaillou, C. Gerente, Y. Andres, D. Wolbert, Bathroom greywater characterization and potential treatments for reuse, Water Air Soil Pollut., 215 (2011) 31–42.

[28] J.G. March, M. Gual, F. Orozco, Experiences on greywater re-use for toilet flushing in a hotel (Mallorca Island, Spain), Desalination, 164 (2004) 241–247.

[29] R. Tandlich, B.M. Zuma, K.J. Whittington-Jones, J.E. Burgess, Mulch tower treatment system for greywater reuse Part II: destructive testing and effluent treatment, Desalination, 242 (2009) 57–69.

[30] I. Ciabatti, F. Cesaro, L. Faralli, E. Fatarella, F. Tognotti, Demonstration of a treatment system for purification and reuse of laundry wastewater, Desalination, 245 (2009) 451–459.

[31] C.-J. Lin, S.-L. Lo, C.-Y. Kuo, C.-H. Wu, Pilot-scale electrocoagulation with bipolar aluminum electrodes for on-site domestic greywater reuse, J. Environ. Eng., 131 (2005) 491–495.

[32] K. Bani-Melhem, M. Al-Shannag, D. Al-Rousan, S. Al-Kofahi, Z. Al-Qodah, M.R. Al-Kilani, K. Bani, M. Rasool Al-Kilani, Impact of soluble COD on grey water treatment by electrocoagulation technique, Desal. Wat. Treat., 89 (2017) 101–110.

[33] M. Pidou, L. Avery, T. Stephenson, P. Jeffrey, S.A. Parsons, S. Liu, F.A. Memon, B. Jefferson, Chemical solutions for greywater recycling, Chemosphere, 71 (2008) 147–155.

[34] L. Hernandez-Leal, H. Temmink, G. Zeeman, C.J.N. Buisman, Removal of micropollutants from aerobically treated grey water via ozone and activated carbon, Water Res., 45 (2011) 2887–2896.

[35] N. Widiastuti, H.W. Wu, H.M. Ang, D.K. Zhang, Removal of ammonium from greywater using natural zeolite, Desalination, 277 (2011) 15–23.

[36] Y. Boyjoo, M. Ang, V. Pareek, Photocatalytic treatment of shower water using a pilot scale reactor, Int. J. Photoenergy, 2012 (2012) 7.

[37] W.H. Chin, F.A. Roddick, J.L. Harris, Greywater treatment by UVC/H_2O_2, Water Res., 43 (2009) 3940–3947.

[38] D.Y.S. Mah, C.H.J. Bong, F.J. Putuhena, S. Said, A conceptual modeling of ecological greywater recycling system in Kuching city, Sarawak, Malaysia, Resour. Conserv. Recycl., 53 (2009) 113–121.

[39] Indah Water Konsortium, 2012. Sewage Facts. Available online at: www.iwk.com.my/v/knowledgearena/sewage (Accessed 3 January 2015).

[40] K.S. Oh, P.E. Poh, M.N. Chong, D. Gouwanda, W.H. Lam, C.Y. Chee, Optimizing the in-line ozone injection and delivery strategy in a multistage pilot-scale greywater treatment system: system validation and cost-benefit analysis, J. Environ. Chem. Eng., 3 (2015) 1146–1151.

[41] R.M.S. Radin Mohamed, M. Nazmi Adnan, M. Arief Mohamed, A.H. Mohd Kassim, Conventional water filter (sand and gravel) for ablution water treatment, reuse potential, and its water savings, J. Sustain. Dev., 9 (2016) 35–43.

[42] J.Y.C. Leong, M.N. Chong, P.E. Poh, Assessment of greywater quality and performance of a pilot-scale decentralised hybrid rainwater-greywater system, J. Cleaner Prod., 172 (2018) 81–91.

[43] J. Berthelin, Microbial Weathering Processes in Natural Environments, in: A. Lerman, M. Meybeck, Eds., Physical and Chemical Weathering in Geochemical Cycles, Springer Netherlands, Dordrecht, 1988, pp. 33–59.

[44] D.A. Vallero, T.M. Letcher, Chapter 10 - Minerals, in: D.A. Vallero, T.M. Letcher, Eds., Unraveling Environmental Disasters, Elsevier, Boston, 2013, pp. 235–273.

[45] CMHC, Final Assessment of Conservation Co-op's Greywater System, CHMC (Canada Mortgage and Housing Corporation), Ottawa, Canada, 2002.

[46] S.A. Prathapar, M. Ahmed, S. Al Adawi, S. Al Sidiari, Design, construction and evaluation of an ablution water treatment unit in Oman: a case study, Int. J. Environ. Stud., 63 (2006) 283–292.

[47] A. Hannouche, G. Chebbo, G. Ruban, B. Tassin, B.J. Lemaire, C. Joannis, Relationship between turbidity and total suspended solids concentration within a combined sewer system, Water Sci. Technol., 64 (2011) 2445–2452.

[48] C.W. Anderson, Turbidity 6.7, USGS National Field Manual for the Collection of Water-Quality Data, U.S. Geological Survey, 2005.

[49] J. Tarun, J. Susan, J. Suria, V.J. Susan, S. Criton, Evaluation of pH of bathing soaps and shampoos for skin and hair care, Ind. J. Dermatol., 59 (2014) 442–444.

[50] K.S. Oh, J.Y.C. Leong, P.E. Poh, M.N. Chong, E. Von Lau, A review of greywater recycling related issues: challenges and future prospects in Malaysia, J. Cleaner Prod., 171 (2018) 17–29.

Appendix

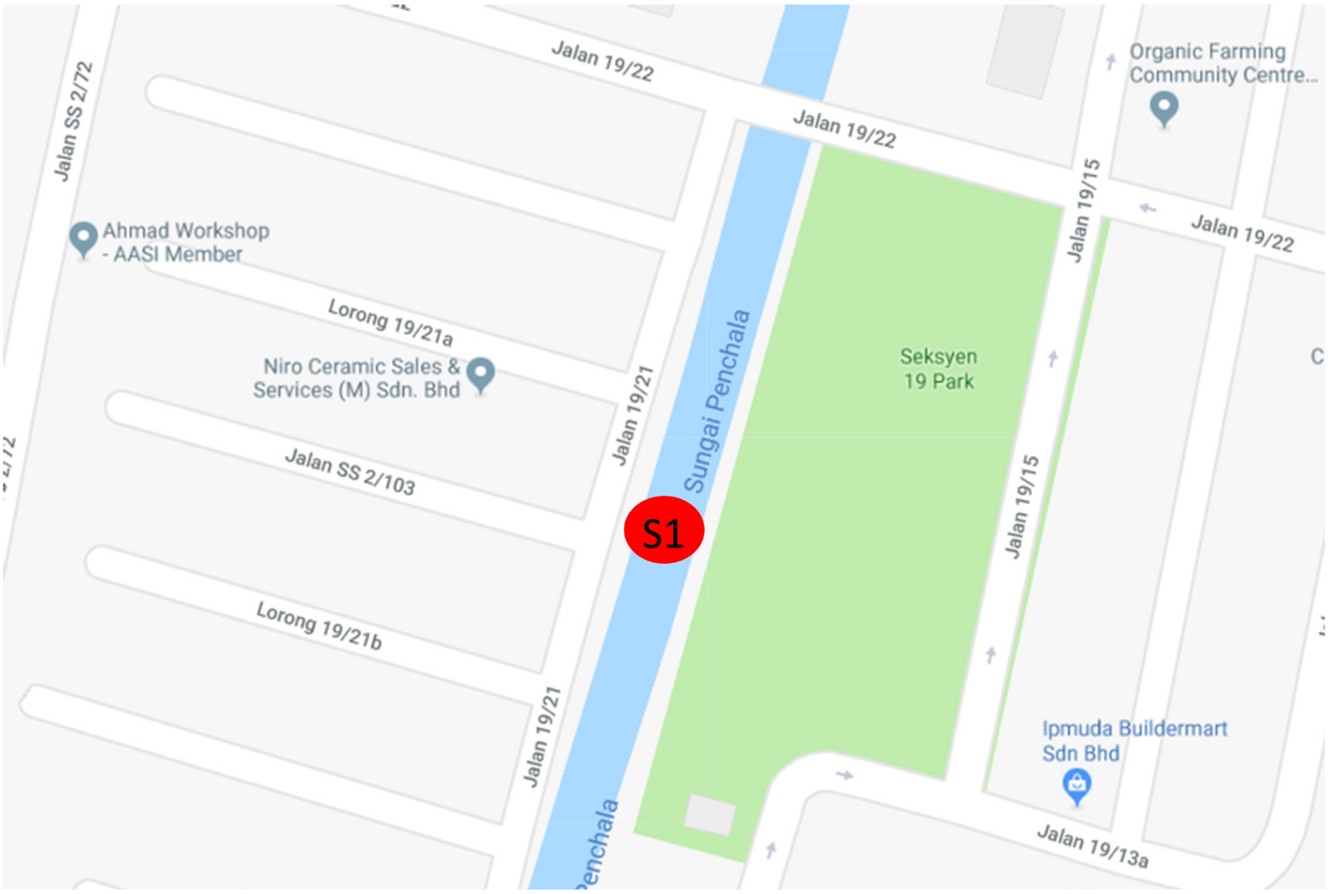

Fig. A1. Sampling site 1 (S1) at Jalan 19/21 (3°7′33.22″N, 101°37′41.77″E).

Fig. A2. Sampling site 2 (S2) at Jalan 19/1 (3°6′57.95″N, 101°37′41.28″E).

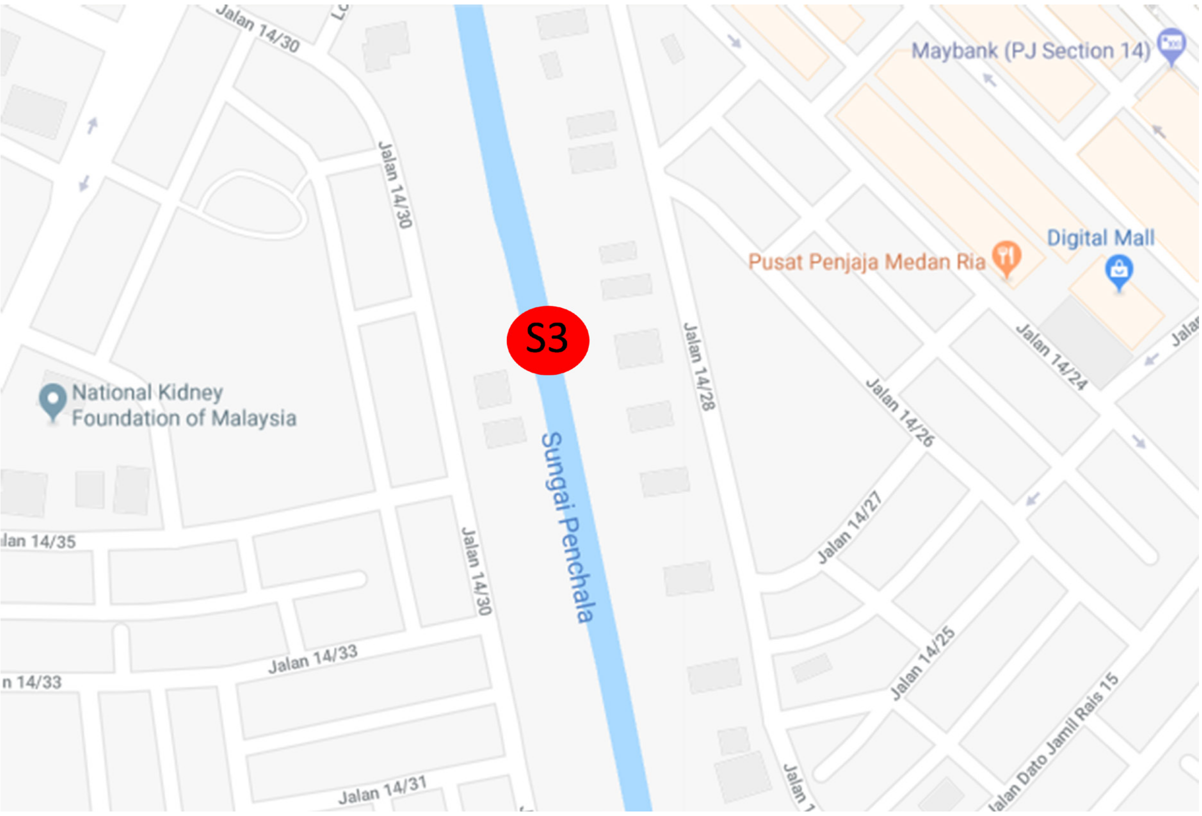

Fig. A3. Sampling site 3 (S3) at Jalan 14/30 (3°6′30.63″N, 101°38′2.70″E).