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Temporal and spatial variation of grey water (sullage) properties from commercial and residential catchments

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ABSTRACT

Water pollution has been one of the major concerns in Malaysia and its increasing severity impacts negatively on the sustainability of water resources. It limits the total water availability dramatically due to the exorbitant cost for treating polluted waters and in some cases, polluted waters are not treatable for consumption. Grey water (sullage) is one of the important sources of pollution, which is released from residential and commercial premises into the rivers without prior treatment. Before initiating measures into developing or implementing grey water reuse and treatment systems, it is more appropriate to conduct a detailed study on the discharged grey water quality and characteristics. The present research studies the chemical, biological and physical characteristics of grey water released from residential and commercial premises near the Melana River, which is located at Skudai, Johor, Malaysia. The variations in parameters, namely, BOD, COD, pH and turbidity, with respect to different days and times (temporal) as well as different sampling sites (spatial) are investigated. The results reveal that grey water quality and characteristics are almost similar to those taken from literature and suggest that the treatment of grey water is necessary for intended reuse purposes.

Keywords: Grey water (sullage); Malaysia; Melana River; Spatial variation; Temporal variation; Water quality

1. Introduction

Water pollution has been one of the major issues faced by the world mainly due to human negligence and poor management. Pollution can cause water bodies unusable for domestic, commercial and irrigation purposes, both at present and in the future. This consequence of pollution is especially accentuated in aquifers, where pollutants are neither degradable nor easily removed and thus accumulate [1]. The problem worsens in areas affected by water scarcity, where there is great pressure on water use and pollutants are less diluted due to the reduced stream flows [2]. To tackle these issues, authorities have been placing much emphasis on treating and reusing grey water. According to [3], grey water, which is produced from kitchen sinks, bathroom sinks, showers and/or baths, and laundry, composes 50–70% of the total wastewater. Given its relatively low organic pollutant content (30%) and high nutrient content (9–20%), grey water has been the best alternative water source, in which, the treatment is relatively easy and the source is relatively abundant as compared to the others [4].

The reuse of grey water without treatment is common, such as garden watering [5,6], landscape irrigation [7], etc.

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The amount of nutrients varies in the composition of grey water and the presence of micronutrients (Zn, Mn and Cu) as well as macronutrients (N, S, P, Ca, K and Mg) can be beneficial to plants [8], e.g., tomatoes [9], silver beets [10], residential lawns, etc. Nevertheless, the treatment of grey water before reuse is encouraged to reducing the risk of harming the environment or living organisms. There are several types or stages of treatment, including biological treatment, physical treatment, chemical treatment, or/and disinfection. The treatment of raw grey water usually begins with a screening process and proceeds to sedimentation to eliminate suspended solids and coarse particles. The pre-treated grey water is then channelled into the main treatment plants comprising biological, physical, chemical or/and extensive treatment units before the final disinfection process takes place.

The understanding of issues pertaining to the safe use and effective treatment of grey water is imperative, especially with the limited source of similar research covering this particular issue in Malaysia. This understanding is required when the concept of grey water reuse and the implementation of grey water treatment are to be employed. In addition, quantities and characteristics of grey water along with potential savings are important factors in the decision making process in grey water reuse and treatment projects. Apart, knowledge of the social constraints concerning domestic grey water reuse and treatment is useful because they prevent further development and integration of reuse and treatment in the urban water system [11].

In Malaysia, the concept of grey water reuse and treatment is still infantile on account of the limited resources and knowledge. Since decades ago, a large number of rivers in Malaysia have been the discharge channels for grey water produced by surrounding residential and commercial premises. The release of a large volume of this grey water into the rivers can cause severe pollution, which might eventually lead to water scarcity. Therefore, it is the intent of this research to study the chemical, biological and physical characteristics of grey water as well as the temporal and spatial variation of grey water quality. The achievement of this objective can help establish management and implementation decisions pertaining to grey water reuse and treatment.

2. Theoretical background

The Water Quality Index (WQI) established by the Department of Environment (DOE) Malaysia can be evaluated using the following formula [12]:

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIpH) \quad (1)$$

where SIDO = Sub Index of Dissolved Oxygen, DO (% saturation); SIBOD = Sub Index of Biochemical Oxygen Demand, BOD (mg/L); SICOD = Sub Index of Chemical Oxygen Demand, COD (mg/L); SIAN = Sub Index of Ammonium, NH_4^+ (mg/L); SISS = Sub Index of Total Suspended Solids (mg/L); SIpH = Sub Index of pH; $0 \le$ WQI ≤ 100.

The best fit equations for the estimation of the sub indexes are demonstrated as follows:

Sub Index of DO (% saturation)

SIDO = 0 for $x \le 8$
SIDO = 100 for $x \le 92$
SIDO = $-0.395 + 0.03\,x^2 + 0.0002\,x^3$ for $8 < x < 92$

Sub Index of BOD (mg/L)

SIBOD = $100.4 - 4.23\,x$ for $x \le 5$
SIBOD = $108 \exp(-0.055\,x) - 0.1\,x$ *for* $x > 5$

Sub Index of COD (mg/L)

SICOD = $-1.33\,x + 99.1$ for $x \le 20$
SICOD = $103 \exp(-0.0157\,x) - 0.04\,x$ for $x > 2$

Sub Index of NH_4^+(mg/L)

SIAN = $100.5 - 105\,x$ for $x \le 0.3$
SIAN = $94 \exp(-0.573\,x) - 5\,|x - 2|$ for $0.3 < x < 4$
SIAN = 0 for $x \ge 4$

Sub Index of TSS (mg/L)

SISS = $97.5 \exp(-0.00676\,x) + 0.05\,x$ for $x \le 100$
SISS = $71 \exp(-0.0061\,x) + 0.015\,x$ for $100 < x < 1000$
SISS = 0 for $x \ge 1000$

Sub Index of pH

SIpH = $17.02 - 17.2\,x + 5.02\,x^2$ for $x < 5.5$
IpH = $-242 + 95.5\,x - 6.67x^2$ for $5.5 \le x < 7$
SIpH = $-181 + 82.4\,x - 6.05\,x^2$ or $7 \le x < 8.75$
SIpH = $536 - 77.0\,x + 2.76\,x^2$ for $x \ge 8.75$

3. Materials and methods

The Melana River is one of the main rivers in Johor, Malaysia. It flows across Skudai, a town in Johor Bahru District, Johor, Malaysia, as demonstrated in Fig. 1. Skudai is part of the new growth corridor of southwest Johor and in accordance with the rapid development in Skudai, the populations have seen a significant growth as well. The Melana River flows across Skudai from 1°34′36.1″N 103°36′34.7″E to 1°30′17.7″N 103°40′51.5″E with an approximate distance of 13.7 km and it is one of the tributaries of the Skudai River. Most residential and commercial premises are located near the Melana River.

As demonstrated in Fig. 2, a total of six sampling sites were selected, in which, sites W1, W2, W3, W4, W5 and W6 are located at Taman Teratai, Taman Sripulai, Taman Sripulai Perdana, Taman Universiti, Taman Mutiararini 2 and Taman Mutiararini 1, respectively. The exact locations and the surrounding conditions of the selected sites are presented in Table 1. The surrounding conditions are classified in terms of living cost (low, medium or high), population density (low or high) and type of catchment area (residential, commercial or mixed). It is notable that in medium cost

Fig. 1. The location of the Melana River.

Fig. 2. Sampling sites (W1–W6).

areas, the population density is relatively higher than that of high cost areas. Out of the six sampling sites, site W2 is located at a mixed residential-commercial area, where residential houses, schools, restaurants, cafes and hotels are densely built, while site W4 is located at a commercial or industrial area, where factories and manufacturing plants are constructed.

A total of 90 samples were collected between 31-Oct 2012 (Wednesday) and 15-Nov 2012 (Thursday) at different times (6–8 am, 12–14 pm and 8–10 pm). Three working days (31 Oct, 7 and 9 Nov 2012), a weekend (4 Nov 2012) and a public holiday (15 Nov 2012) were selected for sampling, as shown in Table 2. Samples were collected from the drainage outlet and sent to laboratory for analyses. Ice was placed inside the auto sampler in order to minimize changes in the sample parameters. A total of 15 sullage parameters were measured using standard methods and calibrated sensors or probes. The selected parameters include chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), dissolved oxygen (DO), temperature, pH, total dissolved solids (TDS), turbidity, ammonium (NH_4-N), ammonia (NH_3), nitrate (NO_3-N), phosphate (PO_4^{3-}), oil and grease, as well as total coliform count and E. coli count. Notably, DO, temperature, pH, turbidity, TDS, NH_4-N, NH_3 and NO_3-N were measured in-situ using the YSI ProDSS multi-parameter water quality meter. The remaining parameters were determined using appropriate methods according to the APHA standards [13,14]. BOD was determined using the 5-d BOD test method (APHA 5210 B), while COD was identified using the closed reflux, titrimetric method (APHA 5220 C). In addition, the wet-oxidation method (APHA 5310 D) was adopted to measure TOC, while the partition-gravimetric method (APHA 5520 B) was employed to determine the content of oil and grease. Apart, was measured using the ion chromatography with chemical suppression of eluent conductivity method (APHA 4110 B) as well as the counts of total coliform and E. coli were evaluated using the standard total coliform fermentation technique (APHA 9221 B and 9225).

The chemical, biological and physical characteristics of grey water were investigated as well as the temporal and spatial variations in four important parameters, namely, BOD, COD, pH and turbidity are studied. Five different days (three working days, a weekend and a public holiday) as well as three different times (morning, afternoon and night) were selected to perform the study of temporal variations. On the other hand, six different sampling sites were selected to conduct the investigation of spatial variations. The collected data were presented in terms of mean, standard deviation, minimum and maximum values. Furthermore, additional data taken from three different references [15–17] were used as the benchmark. In this study, the main software packages that were used for programming and analysis were SPSS Statistics and Microsoft Excel. The collected data were first arranged using Microsoft Excel 2007 and subsequently, the SPSS Statistics was used to build the boxplots. The processed data by the SPSS Statistics were then analysed and discussed. Notably, all the software packages used in this study were licensed under University Technology Malaysia (UTM). Furthermore, the Water Quality Index (WQI) of water samples collected at six different sampling sites was evaluated using the formula and equations given by the Department of Environment (DOE) Malaysia.

Table 1
Exact locations and surrounding conditions of each sampling site

Sampling site	Location	Description
W1	Taman Teratai 1°34′18.31″N, 103°36′47.98″E	Medium cost, high density Residential area
W2	Taman Sri Pulai 1°34′5.55″N, 103°37′3.41″E	Medium cost, high density Mixed residential-commercial area
W3	Taman Sri Pulai Perdana 1°33′26.93″N, 103°37′1.70″E	High cost, low density Residential area
W4	Taman Universiti 1°32′25.22″N, 103°37′16.97″E	Medium cost, high density Commercial area
W5	Taman Universiti 1°31′26.80″N, 103°37′48.85″E	High cost, low density Residential area
W6	Taman Mutiara Rini 1°31′32.10″N, 103°38′42.03″E	High cost, low density Residential area

4. Result and discussion

4.1. Grey water characteristics

Grey water quality fluctuates significantly during the 5-day sampling at different hours and locations. COD

Table 2
Sampling day and time

Wednesday			Sunday			Wednesday			Friday			Thursday		
31/10/12			4/11/12			7/11/12			9/11/12			15/11/12		
Working day			Weekend			Working day			Working day			Public holiday		
M_1	A_1	N_1	M_2	A_2	N_2	M_3	A_3	N_3	M_4	A_4	N_4	M_5	A_5	N_5
7 am	1 pm	9 pm	7 am	1 pm	9 pm	7 am	1 pm	9 pm	7 am	1 pm	9 pm	7 am	1 pm	9 pm

ranges from 3 to 563 mg/L, while BOD varies from 0.1 to 277.5 mg/L. As compared to those in [15–17], the grey water samples are relatively lower in both COD and BOD, as shown in Table 3. Correspondingly, COD:BOD ratio is reported to be 5.73 ± 3.15, which is higher than that of typical domestic sewage (2.2 ± 0.6). This subsequently implies that the produced grey water is probably to have a higher non biodegradable content than sewage [18]. Nutrients are present in lower concentrations, where ammonium ranges from 0.08 to 7.23 mg/L, nitrate varies from 0.27 to 766.70 mg/L and phosphate vacillates from 0.02 to 1.71 mg/L. The average ratio of COD:N:P is determined to be 100:9.87:0.27, showing that the released grey water is deficient in both nitrogen and phosphorus as compared to the benchmark ratio (100:20:1) [18]. These indirectly indicate that the discharged amounts of urines, which contain nitrogen compounds, as well as detergents and soaps, which contain phosphorus compounds, are relatively low [19]. Furthermore, the physical pollution of the grey water samples varies considerably with average turbidity of 31.25 ± 93.12 NTU. In addition, the concentrations of oil and grease are reported to be slightly higher in average (2.78 mg/L) than those in [15] (<2 mg/L). This suggests that a considerable amount of kitchen wastes are probably released from the surrounding commercial premises, including restaurants, cafes and hotels, into the river. While most of the available tests for total coliform and E. Coli are measured in CFU/100 ml, the tests used in the present study are measured in MPN/100 ml. According to Cho, Han, Park [20] as well as Gronewold and Wolpert [21], the bacteria counts measured in MPN/100 ml are usually higher than those measured in CFU/100 ml. Though, in the present study, the average counts of total coliform and E. coli in the grey water samples are slightly lower than those in [17] with values of 1269.5 and 939.86 MPN/100 ml, respectively.

4.2. Temporal and spatial variations of grey water quality

This study investigates the temporal and spatial variations of grey water quality, in which temporal variations refer to the variations in parameters with respect to different sampling times and days, while spatial variations refer to the variations in parameters with respect to different sampling times and sites. As mentioned before, three different times were generally adopted, namely, morning (M), afternoon (A) and night (N). Five different days (D) and six different sampling sites (W) were selected, as elaborated in the previous section. Due to space constraints, parts of the results are selected and presented in this section, namely, chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH and turbidity.

The maximum COD of water samples retrieved during the day (morning and afternoon) is relatively higher than those taken at night, as depicted in Fig. 3. This suggests

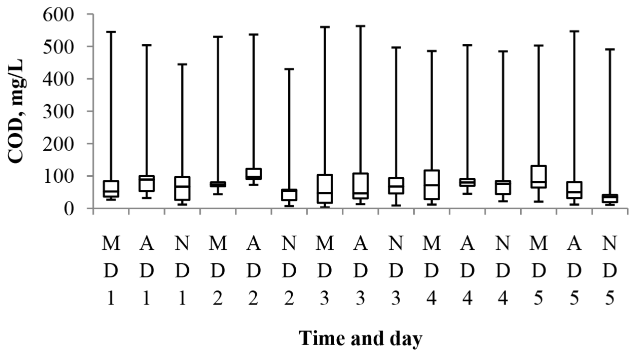

Fig. 3. Temporal variations in COD (mg/L), where, M: morning, A: afternoon, N: night and D: day.

Table 3
Grey water quality

Parameter	Min.	Max.	Mean	Std. dev.	Atasoy, Murat, Baban [15]	Hocaoglu, Güçlü, Emine [16][b]	Jefferson, Palmer, Jeffrey [17][a]
COD (mg/L)	3.00	563.00	133.48	171.25	245	295	451 ± 289
BOD (mg/L)	0.10	277.50	23.29	54.44	90	111	146 ± 54.3
TOC (mg/L)	8.54	409.09	59.15	110.25	NA	NA	72.6 ± 79.3
DO (mg/L)	0.23	6.36	1.72	1.52	NA	NA	NA
DO (%)	3.00	80.00	22.07	19.61	NA	NA	NA
Temperature (°C)	26.05	31.04	28.14	1.11	22	NA	NA
pH	5.24	7.75	6.86	0.41	7.1	7.2	7.47 ± 0.29
TDS (mg/L)	0.00	2.46	0.16	0.28	301	NA	NA
Turbidity (NTU)	–6.60	834.70	31.25	93.12	NA	NA	100.6 ± 109
Ammonium (mg/L)	0.08	7.23	0.65	0.96	1.3	1.6	NA
Ammonia (mg/L)	0.00	0.01	0.00	0.00	NA	NA	NA
Nitrate (mg/L)	0.27	766.70	13.18	80.21	NA	NA	NA
Phosphate (mg/L)	0.02	1.71	0.36	0.53	7.3	7.3	0.35 ± 0.23
Oil and grease (mg/L)	1.00	25.00	2.78	5.69	<2	NA	NA
Total coliform	23.60	2419.6	1269.5	986.52	13634c	NA	7,387c
E. coli	2.00	2419.6	939.86	992.77	NA	NA	2,022c

[a]Bath and shower; [b]Including kitchen; [c]CFU/100ml

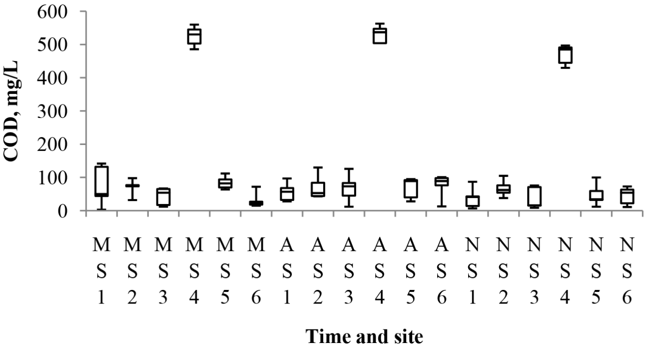

Fig. 4. Spatial variations in COD (mg/L), where, M: morning, A: afternoon, N: night and S: site.

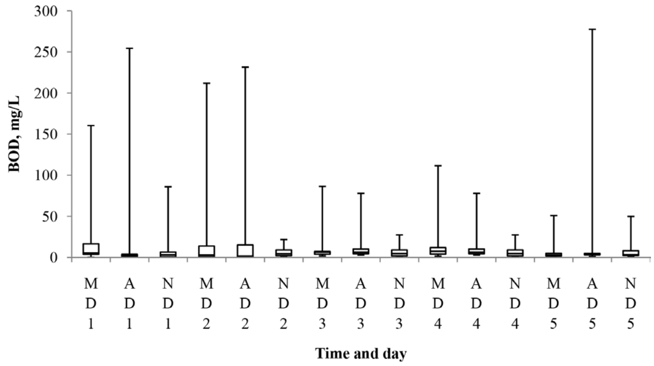

Fig. 5. Temporal variations in BOD (mg/L), where, M: morning, A: afternoon, N: night and D: day.

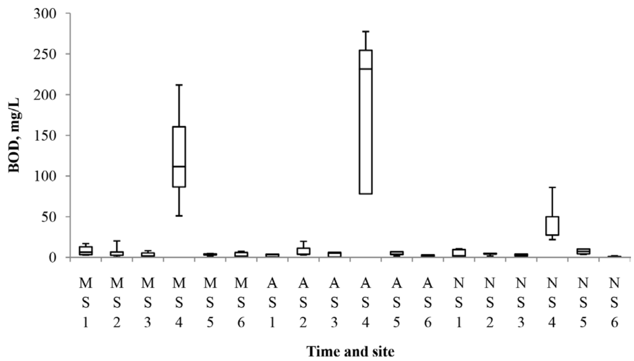

Fig. 6. Spatial variations in BOD (mg/L), where, M: morning, A: afternoon, N: night and S: site.

that residential and commercial activities are at the peak during the day, where the discharge of grey water containing organic and inorganic pollutants into the river, is more prevalent [22]. At night, a relatively lower amount of grey water is produced and thus, the amounts of oxygen needed in the degradation of organic compounds as well as the oxidation of inorganic compounds are relatively lower [23]. Apart, no significant difference exists between COD of water samples taken on different days. In terms of spatial variations, COD of water samples obtained from sampling site W4 is significantly higher than those taken from sampling sites W1, W2, W3, W5 and W6, as demonstrated in Fig. 4. This can be explained by the activities conducted near site W4, where it is surrounded by a number of manufacturing plants and factories, as stated by Noukeu, Gouado, Priso [24] that BOD and COD found in untreated effluents from industries are normally 10–100 times higher than those of domestic wastewater. A higher volume of organic as well as inorganic compounds are likely to have been discharged from these factories into the Melana River, which consequently leading to the significant increase in COD as compared to the other sampling sites, where they are mostly located at residential areas.

Water samples collected in the morning and afternoon show relatively higher maximum BOD as compared to those collected at night, as depicted in Fig. 5. This suggests that the load of organic compounds is the highest during the day in accordance with normal working hours, where residential and commercial activities are more likely to have taken place. Following the increasing load of organic compounds during the day, pollutant degradation by aerobic microorganisms is subsequently prompted, thereby increasing the BOD. In addition, water samples collected on weekend and public holiday exhibit relatively higher maximum BOD. Since BOD is much related to the presence of organic pollutants and it is known that organic pollutants mostly come from kitchen wastes, graden waste, etc. [25], it can be inferred that during weekend and holiday, residential activities, such as cooking, gardening, etc., are more prevalent and could be one of the contributing factors leading to the increase in BOD. Furthermore, as compared to those retrieved from other sampling sites (Fig. 6), water samples taken from sites W2 and W4 demonstrates relatively higher BOD mainly due to its surrounding commercial and industrial activities. As claimed by Noukeu, Gouado, Priso [24], BOD and COD found in untreated effluents from food processing industries are normally 10–100 times higher than those of domestic wastewater. Several residential houses, schools, restaurants, cafes and hotels can be found in the area near sampling site W2, while multiples industries and factories can be spotted in the area near sampling site W4. An increase in BOD signifies an increase in demands for oxygen by aerobic bacteria to decompose organic pollutants. Therefore, when organic pollutant concentration increases, pollutant degradation by aerobic microorganisms is induced, which susequently increases the demands for oxygen and hence the BOD. Although BOD is an aggregate measure of the concentration of microbially degradable pollutant in water, BOD conveys no information about the identities of specific compounds or their individual degradation rates [26].

As seen from Fig. 7, the minium pH of water samples obtained in the afternoon is relatively lower compared to those taken in the morning and at night, indicating that a higher volume of acidic effluents are released in the afternoon. Apart from that, water samples retrieved in the afternoon of days 1, 2 and 5 (working day, weekend and public holiday, respectively) exhibit relatively lower minimum pH, implying higher acidicity. The minimum pH of water samples collected from sampling sites W2 and W4 is comparatively lower (more acidic) than those from the other sites, as illustrated in Fig. 8. Residential houses, restaurants, cafes and hotels are found near sampling site W2, while factories (food, metal and printing factories) are

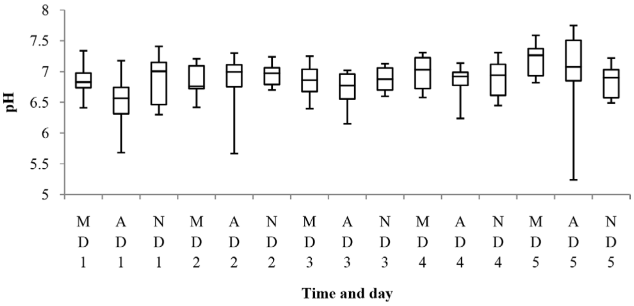

Fig. 7. Temporal variations in pH, where, M: morning, A: afternoon, N: night and D: day.

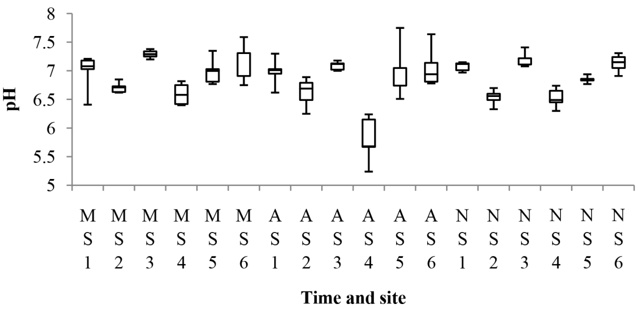

Fig. 8. Spatial variations in pH, where, M: morning, A: afternoon, N: night and S: site.

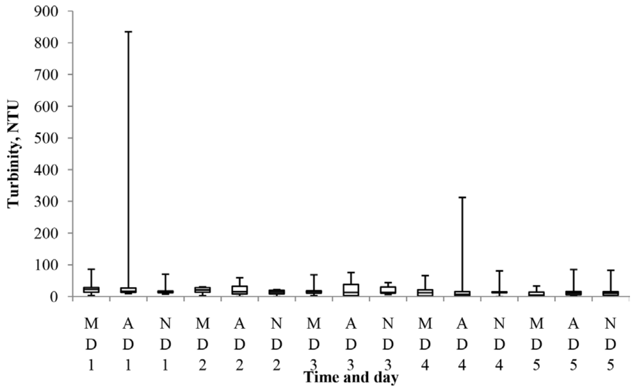

Fig. 9. Temporal variations in turbidity (NTU), where, M: morning, A: afternoon, N: night and D: day.

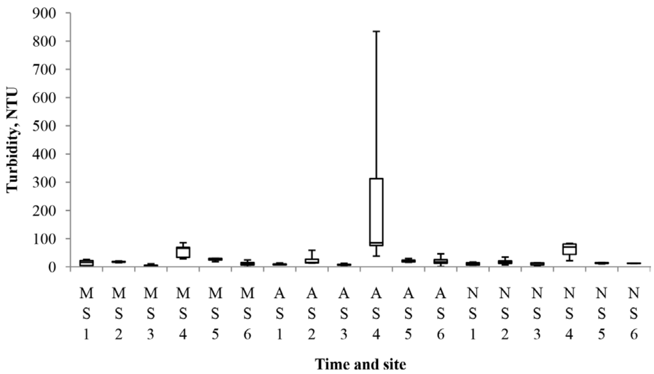

Fig. 10. Spatial variations in turbidity (NTU), where, M: morning, A: afternoon, N: night and S: site.

seen around sampling site W4. Food wastes [27] as well as industrial wastes (especially from metal and mining industries) [28] can be the probable causes of the elevated acidity. According to [27], the pH of food waste ranges from 4.7 to 6.1and organic acid concentration ranges from 24 to 81 mmol kg^{-1}. Shi [28] stated that metal and mining industries normally produce acidic effluents, which lead to lower pH. Therefore, these could be the probable reasons leading to the decrease in the pH of water samples at sampling sites W2 and W4.

One of the most important parameters which determines the physical water quality is turbidity. Fig. 9 and Fig. 10 demonstrate the temporal and spatial variations in turbidity of collected water samples. As compared to morning and night, the maximum turbidity of water samples taken in the afternoon is relatively higher (Fig. 9). Since a strong linear relationship exists between turbidity and concentration of suspended solids [29], it can be deduced that the discharged amount of suspended solids is relatively higher in the afternoon. Apart, samples collected on working days (days 1 and 4) exhibit significantly higher maximum turbidity as compared to those obtained on the other days. Furthermore, samples retrieved from sampling sites W2 and W4 exhibit relatively higher maximum turbidity, denoting a higher amount of suspended pollutants are released by residential and commercial premises, as shown in Fig. 10. In addition, referring to the printing factory located near sampling site W4, the release of coloured dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM) and dyes can as well increase the turbidity of water [30]. In this study, it is notable that negative turbidy can be rounded off to zero turbidity.

4.3. Evaluation of Water Quality Index (WQI)

The quality of surface water in Malaysia is determined by the Water Quality Index (WQI) and categorised into several classes (I, II, III, IV and V) based on the National Water Quality Standards for Malaysia established by the Department of Environment (DOE) [12], as demonstrated in Table 4. Class I refers to clean water, where practically, no treatment is needed. Grey water normally falls under the class of II or III, where conventional or extensive treatment is necessarily needed. For class IV or V, water is badly or severely polluted and proper treatment is compulsorily required.

Temporal and spatial variations of grey water quality have been investigated and it has been discovered that the release of wastewater is at the peak in the afternoon regardless of the sampling locations. Therefore, in this context, water samples collected in the afternoon at six different sampling sites (Table 5) are utilized in evaluating the WQI based on the formula and equations provided. Notably, total suspended solids (TSS), which are required in the evaluation, are not measured in the present study. To address these, turbidity can be converted into TSS applying the equation, y, suggested by [31]. It should be stressed that the adopted equation is an approximate conversion with satisfactory accuracy.

Using the formula and equations presented in the previous section, the WQI of water samples collected at different

Table 4
Department of Environment (DOE) Water Quality Index Classification [12]

Class				
I	II	III	IV	V
>92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0

Table 5
Water samples collected in the afternoon at six different sampling sites

Sampling site	W1	W2	W3	W4	W5	W6
DO (%)	13.70	10.60	19.00	8.50	11.10	24.80
BOD (mg/L)	3.63	11.19	5.18	231.50	3.69	1.54
COD (mg/L)	57.00	53.00	73.00	537.00	89.00	89.00
NH_4^+ (mg/L)	0.48	0.33	0.28	2.73	0.36	0.26
Turbidity (NTU)	8.40	15.45	6.00	85.20	18.30	17.60
TSS (mg/L)	6.80	12.50	4.85	68.93	14.80	14.24
pH	7.01	6.69	7.12	5.68	6.74	6.94

locations is evaluated, as shown in Table 6. It shows that the water samples retrieved from sampling sites W1, W2, W3, W5 and W6 are defined under class III, while those collected at sampling site W4 fall under class V, indicating that the nearby river water could have been severely polluted. As mentioned, W2 is located at a mixed residential-commercial area, while W4 is located at a commercial area surrounded by a number of industries and factories. Hence, the WQI of water samples taken from W2 and W4 can be seen to be relatively lower than those of the other sampling sites.

5. Conclusion and recommendations

The Melana River is one of the main rivers in Skudai, a town located in Johor, Malaysia. Residential and commercial activities are prevalent at most of the areas near the river. The chemical, biological and physical analyses of the collected water samples revealed that grey water produced by nearby premises contains considerable levels of chemical and biochemical oxygen demands (COD and BOD), pH, turbidity as well as total coliform and E. coli. The levels of these parameters are almost similar to (slightly lower) those reported by previous researchers, indicating that a proper treatment of grey water is recommended to avoid the risks of jeopardising the life of aquatic organisms as well as the safety of consumers. Five different days (three working days, a weekend and a public holiday) and three different times (morning, afternoon and night) were selected to study the temporal variations of grey water quality, while six different sampling sites were selected to investigate spatial variations of grey water quality. The variations in four important parameters, namely COD, BOD, pH and turbidity are investigated. It can be deduced that during weekend and holiday, the load of organic pollutants (BOD) is relatively higher and pH of the discharged grey water is relatively lower (acidic) than those of normal working days. On the contrary, the released grey water exhibits relatively higher turbidity during working days. Furthermore, grey water samples collected in the afternoon demonstrates relatively higher COD, BOD and turbidity as well as lower pH (acidic) compared to those in the morning and at night. In terms of spatial variations, grey water sampled at sites W2 and W4 (mixed residential-commercial and commercial areas, respectively) shows elevated levels of COD, BOD and turbidity as well as relatively lower pH (acidic) as compared to other sites. The Water Quality Index (WQI) of water samples collected at six different sampling sites has been evaluated, showing that water samples taken from sampling sites W1, W2, W3, W5 and W6 fall under class III, while those retrieved from W4 fall under class V. The overall results suggest that the treatment of grey water is highly recommended for intended reuse purposes. Given the detailed analyses of the results, developing and implementing an effective grey water treatment system in Malaysia can be possible in the near future. Notably, the setbacks of such implementation include high installation, operating and maintenance costs. Hence, proper planning and development are required. We can begin with the implementation of a preliminary grey water treatment unit, followed by the execution of a small-scale grey water treatment system and lastly, the set-up of a large-scale grey water treatment and management system. At the preliminary stage, simple treatment steps are favourable as these treatment units incur comparatively lower installation and maintenance costs. Technically, integrating filtration, aeration and disinfection to form a preliminary compact grey water treatment unit can be cost-effective at the preliminary stage, in which, initially, physical filtration can be utilized to remove suspended or dissolved particles, followed by the use of aeration to promote microbial pollutant degradation and lastly, disinfection can be executed either via chlorination or ultraviolet (UV) disinfection to eradicate pathogenic bacteria. After conducting an extensive investigation of the preliminary treatment unit, we can proceed with the development and implementation of a small-scale decentralized treatment system. This system uses natural or mechanical parts to collect, treat, discharge or reclaim wastewater. It can be installed in densely populated residential areas (e.g. high-rise buildings) or sparsely populated residential areas to treat grey water directly and effectively within houses. Subsequently, with the in-depth knowledge of implementing and maintaining grey water

Table 6
Evaluated Water Quality Index (WQI)

Sampling site	W1	W2	W3	W4	W5	W6
SIDO	4.72	2.74	9.06	1.65	3.03	15.01
SIBOD	85.05	57.24	80.71	–23.15	84.79	93.89
SICOD	39.81	42.70	29.82	–21.46	21.91	21.91
SIAN	63.80	69.45	71.10	16.02	68.28	73.20
SISS	93.46	90.23	94.60	47.66	88.95	89.26
SIpH	99.33	98.37	98.99	85.25	98.67	99.52
WQI	60.01	54.97	59.78	12.79	56.60	61.85
Class	III	III	III	V	III	III

treatment systems, the set-up of a large-scale centralized grey water treatment and management system involving residential and commercial buildings (e.g. restaurants, hotels, factories, etc.) can be possible.

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Author Contributions

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