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Quantifying Pollutants from Household Wastewater in Kuching, Malaysia

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Abstract: In Malaysia, septic tank effluents were discharged into rivers. However, knowledge on quantity of household wastewater pollutants was incomplete. Therefore, water consumption, wastewater flow and pollutants concentrations and loadings were investigated. The residential areas studied were the high income area of De Summit Condominium (DS), medium income areas of Tabuan-Jaya (TJ) and Taman Satria-Jaya (TSJ) and low income areas of RPR Batu-Kawa (RPR) and Taman Malihah (TM). Results indicated that wastewater flows ranged from 95-122 L/c/d which were 33-67% of the water consumption rates. DO and BOD_5 ranged from 0.7-4.4 mg/l and 67-135 mg/L respectively. Nitrate-nitrogen was the highest at DS (0.19 mg/L). Reactive phosphorus ranged from 4.4-12.7 mg/L. In all areas, *E. coli* ranged from 10^6-10^7 cfu/100mL. Mean loadings of BOD_5, reactive-phosphorus, nitrate-nitrogen and *E. coli* were found to be 8-14 g/c/d, 0.6-1.0 g/c/d, 4.3-9.6 mg/c/d and 3.3-7.2x10^9 CFU/c/d respectively. Reactive phosphorus loading was 1.6 times higher in the low income areas (RPR and TM) when compared to the other areas. With the area population of 44,516, 10x10^6 L/d of water was consumed, 5x10^6 L/d of wastewater produced contributing to 511 kg/d of BOD_5, 31 kg/d of reactive phosphorus, 1.8x10^{14} *E. coli*/d to surface water around Kuching.

Key words: Household wastewater · Water quality · Sewage · Wastewater treatment

INTRODUCTION

Discharge of household wastewater into surface water may present a variety of concerns such as high biochemical oxygen demand, significant nutrient inputs, high suspended solids, ecosystem disturbance and health hazard due to potential pathogens. Household wastewater consists of as black water (urine and faeces) and grey water from the kitchen, bathroom and washing machine. Studies of household wastewater generation in England and Malta showed that wastewater was high in organic matter, ortho-phosphorus and ammonia [1]. Most studies of household wastewater focused on chemical parameters but not the microbial parameters [1-3].

Kuching, being the capital city of Sarawak with relatively more job opportunities and educational facilities is growing rapidly. As the population increases, household wastewater discharges also increase resulting in an increasing pressure on the natural cleansing ability of the rivers. In the city, individual septic tank is the most common form of sewerage system for most of the residential areas. The septic tank effluents were typically discharges into municipal storm drains. However, septic tank was reported to be ineffective in reducing nutrients loading of wastewater [4]. In a pilot study of the Danish Cooperation for Environment and Development (DANCED) in collaboration with Natural Resources and Environment Board (NREB) Sarawak through the Sustainable Urban Development Project, household wastewater was identified the most significant source of pollution of the Sarawak River fronting Kuching City [5]. It was the first attempt to identify the most significant sources of pollution and the quantity of wastewater flow in Kuching City. However, water quality parameters such as dissolved oxygen, nitrate, phosphate and *E. coli* were not included in the investigation [5]. Health effects criteria signify that swimming in marine waters of as few as 10 *E. coli*/100ml is risky [6]. *E. coli* is one of the coliform bacteria commonly found in the intestinal tract of warm-blooded animals. It is more representative of faecal contamination than other coliforms. Each person discharges 100-400 billion coliform organisms per day, in addition to other kinds of bacteria [7]. Furthermore, knowledge on instantaneous maxima and minima of wastewater flow for Kuching City which are important for the establishment of design flows and calculation of pipe diameters and gradients [1] were also lacking.

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Therefore, the objectives of this study were to determine the water consumption, quantity and quality of household wastewater and to quantify the loadings of organic matter, phosphate, nitrate and *E. coli* from major housing areas in Kuching City.

MATERIALS AND METHODS

Study Area: The residential areas selected for the study were De Summit Condominium (DS), Tabuan Jaya (TJ), Taman Satria Jaya (TSJ), RPR Batu Kawa (RPR) and Taman Malihah (TM). They were classified as low-, middle-and high-income areas based on the type and value of the properties where DS is a condominium, TJ and TSJ are mostly medium cost terrace and semi-detached houses and RPR and TM are low-cost terrace houses. Sub-areas were selected for water sample collection and a general household survey was also carried out at the residential areas to gather demographic data.

Experimental Design and Sample Collection: Flow and water quality data were collected from subareas of the five residential areas, between May and September of 2002 on dry days. The timing of data collection represented the worse case scenario of household wastewater pollution whereby wastewater from households was minimally diluted by stormwater. The experimental design was randomized complete block design with areas as treatment and flow rates as block. Sampling point of the DS condominium was at the outlet of the discharge point from the sewerage plant i.e. Imhoff tank. For the other four residential areas, wastewater was collected at the main trunk drains (stormwater drains). For each area, flow rates were determined for a duration of 13-16 hours at about one to two hours interval. Based on the low (L), medium (M) and high (H) flow rates, composite grab samples of wastewater were collected at the respective residential area sampling points. Each station was visited three times during the sampling period. pH, temperature and dissolved oxygen (DO) data were collected *in-situ* using an YSI DO meter. Samples collected were wrapped with aluminium foil and transported to the laboratory at 4 °C for immediate analysis.

Sample Analysis: Five-day biochemical oxygen demand (BOD_5), nitrate-nitrogen and reactive phosphorus were analyzed according to the Standard Methods [8]. Hach Spectrophotometer DR2010 [9] was used to determine nitrate-nitrogen and reactive phosphorus concentrations. For *E. coli* analysis, spread plate method was used [8]. Modified EMB agar was used as growth medium [10] with 0.1 % peptone as dilution water. Plates were incubated at 37 °C for 24 hours. All samples were analyzed in triplicate.

Data Analysis: Significant difference in *per capita* flow and loadings of BOD_5, reactive phosphorus and nitrate-nitrogen between the residential areas were analyzed using 2-way ANOVA and multiple comparisons were performed by using Tukey's test. All analyses were carried out using SPSS version 14.0 package.

Estimation of Total Pollutant Loading: Total pollutant loading from DS, RPR, TM and two census zones where TJ and TSJ falls into were estimated based on the population census of the year 2000 [11]. Under the census zone, Tabuan Dusun, Tabuan Desa and Tabuan Jaya Phase 4 were grouped under one census zone (designated here as Zone A). Taman Satria Jaya, Stampark, Phoenix Garden and Tabuan Height were grouped under another census zone (designated here as Zone B).

Computations: *Per capita* flow rate was computed according to equation 1,

$$F = 60\, f\, t / n \quad (1)$$

where F is per capita flow rate (L/c/d), f is average flow rates (L/min), t is measurement duration (h), n is number of occupants. Pollutant load was computed according to equation 2,

$$L = FC \quad (2)$$

where L is per capita pollutant loading (mg/c/d), F is per capita flow rate (L/c/d) and C is pollutant concentration (mg/L). Total pollutant loading was computed according to equation 3,

$$L = n\, FC \quad (3)$$

where L is pollutant loading (mg/d for BOD, phosphorus and nitrogen and CFU/d for *E. coli*), F is wastewater flow (L/c/d), n is number of occupants and C is pollutant concentration (mg/L or CFU/L).

RESULTS AND DISCUSSION

Survey Results: Results of the household survey are shown in Table 1. TJ, RPR and TM have been occupied for more than 10 years, with RPR as long as 20 years. On the other hand, DS was a new housing area.

Table 1: Demographic data of the sub-areas of the five residential areas in Kuching

	DS	TJ	TSJ	RPR	TM
No. of household studied	61	25	14	46	36
Duration of occupancy (longest)	0.6 (1)	9 (11)	7 (8)	14.6 (20)	7 (12)
Occupants/household	2	5	5	5	6
Adults per household	2	4	3	4	4
Children per household (<12 years old)	<1	1	2	1	2
Total occupants	122	125	70	230	216
Water consumption (L/c/day)	191	264	180	285	371
Monthly income (RM)	5140	4122	3375	1780	2500

Table 2: *Per capita* wastewater flow and pollutants loading from the five residential areas in Kuching

	Mean (Range) values				
Parameter	DS	TJ	TSJ	RPR	TM
Flow (L/c/d)	104^{ab}(41-149)	113^{bc}(77-163)	120^{c}(67-179)	95^{a}(47-126)	122^{c}(74-163)
BOD_5 (mg/c/d)	7943^{a}(2862-10824)	11634^{b}(6599-16853)	11201^{b} (6615-17715)	10878^{b}(4928-14646)	14323^{c} (8318-19011)
Phosphorus (mg/c/d)	700^{a}(456-1174)	577^{a}(437-843)	648^{a}(525-876)	1020^{b}(542-1330)	1016^{b}(979-1064)
Nitrate-N (mg/c/d)	9.6^{a}(7.9-12.2)	4.3^{b}(1.8-6.0)	5.5^{bc}(2.6-8.9)	5.1^{bc}(2.7-6.6)	6.8^{c}(3.7-11.0)
E. coli (lg CFU/c/d)	9.4^{a}(8.9-9.8)	9.6^{ab}(9.5-9.8)	9.7^{b}(9.3-10.2)	9.8^{b} (9.5-9.9)	9.8^{b}(9.5-9.9)

* Means in the same row with the same superscript are not significantly different at 5% level.

The average number of occupants in a household was five people in TJ, TSJ and RPR whereas TM had 6 occupants per household with the addition due to children. The high-income DS condominium had fewer occupants in a household and most of them were working professional couples.

Among the residential areas, the residents of DS and TSJ consumed the least water of less than 200 L/c/d and TM the highest consumption (Table 1). The low water consumption in DS and TSJ was probably due to the residents spending less time at home during day time as women also participated in the labour market. Therefore, they are less engaged in water consuming activities especially meal preparations and washing. The high water consumption of residents in TM is most likely due to the higher number of housewives who spent more time at home preparing meals and washing more frequently as evidenced by the relatively high flow pattern throughout the day (Fig. 1). In the present study, water consumption in DS and TSJ were lower compared to the reported consumption of 240 l/c/d in Denmark [3] while that in TJ, RPR and TM were higher. This is most likely due to the amount of time the residents spent at home which affected the amount of water use. The mean monthly total household income of low-income areas was below RM3000 and the middle-income areas of TJ and TSJ has income of between RM 3,000 to RM 5,000. DS falls in the high-income area generating above RM 5,000 monthly.

Wastewater Quantity: Wastewater flow rate is shown in Figure 1. In DS and TSJ, there were only two peaks a day, morning and evening. TM and TJ showed an additional peak between 1-2 pm. However, RPR showed the most number of peaks that was not observed in other housing areas most likely due to more frequent washing by housewives in addition to lunch preparation. TM recorded the highest wastewater flow and RPR the lowest. The mean per capita wastewater flow of 95 to 122 L/c/d (Table 2) was within the range of 59 to 378 l/c/d reported in the pilot studies [4] and lower than those in USA (133-180 L/c/d) but close to that in UK (101 L/c/d) and Malta (95 L/c/d) [1]. The lower wastewater flow in the present study as compared to USA could be due to low usage from bathtub, showers and dishwashers. The common practice in Kuching was to fill up buckets to bathe and dishwasher was not commonly used. The wastewater flow was 33-67% of the water consumed. All areas except TSJ were lower than that estimated by Metcalf and Eddy [7], that is, 60-90% of the water consumed becomes wastewater. This could be due to leakage in the household pipes which residents may not be aware of. Furthermore, some of the water used for car-washing and most of those from garden plant-watering did not get into the drainage system and for low income areas, there may be some seepage in the broken storm drain.

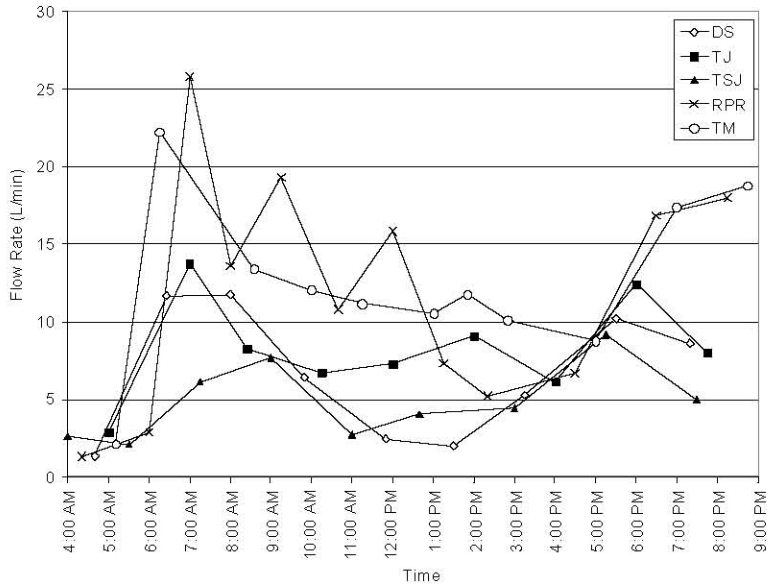

Fig. 1: Flow rates pattern of the five residential areas in Kuching City

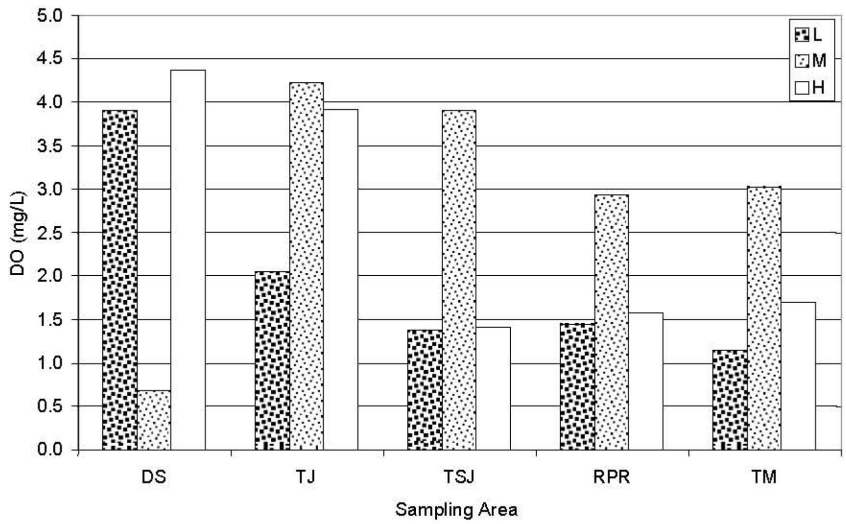

Fig. 2: Dissolved oxygen (DO) concentrations of wastewater from the five residential areas during low (L), medium (M) and high (H) flow

Temperature, pH and DO: Table 3 shows temperature and pH of the wastewater during the duration of sampling. The range of mean temperature at the five residential areas was 28.0-29.5 °C. Temperature was found to be higher during low flow than high flow. At DS, temperature was the lowest. pH of all the areas were close to neutral.

Figure 2 shows DO at different flow rates. For all the areas except DS, the highest DO occurred during medium flow and the lowest during low flow. However, at DS, DO was the lowest at medium flow. This is most likely due to oxygen being used up to break down organic matter and also the oxidation of ammonia to nitrate as the corresponding concentration of BOD_5 was the lowest (Fig. 3) and nitrate was the highest at medium flow rate (Fig. 4). At DS, Imhoff tank system was used where effluent from the sedimentation passed through a rock filter bed where treatment by microorganism occurred. But for septic tank system of the other areas, there was no rock filter bed for such purposes. DO was found to be low especially during low and high flow of TSJ, RPR and TM. Regardless of the flow, DO were below 5 mg/L, the minimum for proper growth of warmwater fish species [12]. It was reported that at this DO level, fish growth is slow for long term exposure.

Table 3: Temperature, pH and *E. coli* concentrations of household wastewater during low (L), medium (M) and high (H) flow

	Temperature (°C)			pH			*E. coli* concentration (CFU/100mL)		
Area	L	M	H	L	M	H	L	M	H
DS	29.5	29.0	26.0	7.23	7.24	7.33	$2.19x10^6$	$1.91 x10^6$	$4.45x10^6$
TJ	31.5	30.0	27.0	7.22	7.51	7.45	$4.43 x10^6$	$6.25 x10^7$	$1.80x10^6$
TSJ	29.0	30.0	27.0	7.58	7.37	7.62	$3.87 x10^6$	$1.25 x10^7$	$2.07x10^6$
RPR	32.0	27.0	27.0	6.97	7.32	7.26	$1.85 x10^7$	$8.65 x10^6$	$2.59x10^6$
TM	32.0	28.0	27.0	6.90	7.47	6.96	$4.20 x10^6$	$6.61 x10^6$	$5.81x10^6$

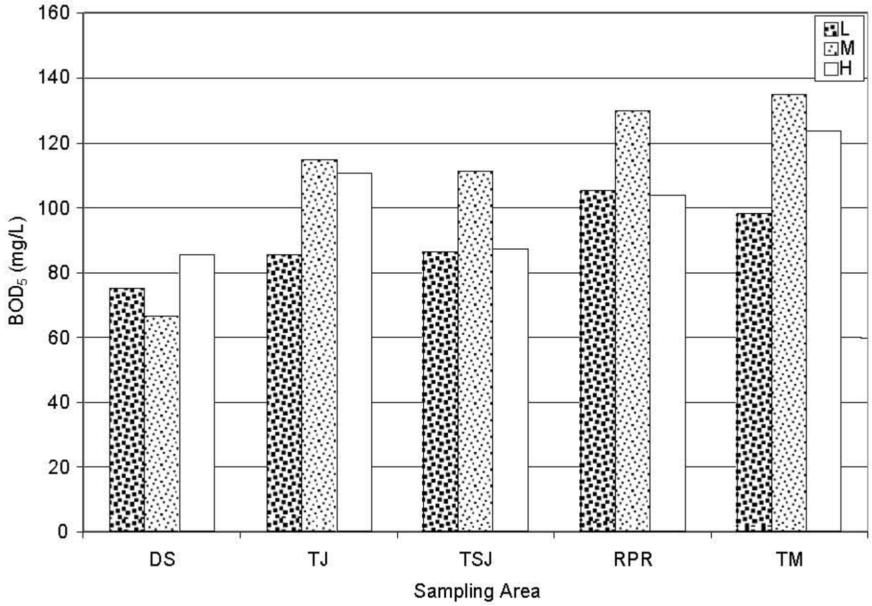

Fig. 3: BOD_5 concentrations of wastewater from the five residential areas during low (L), medium (M) and high (H) flow.

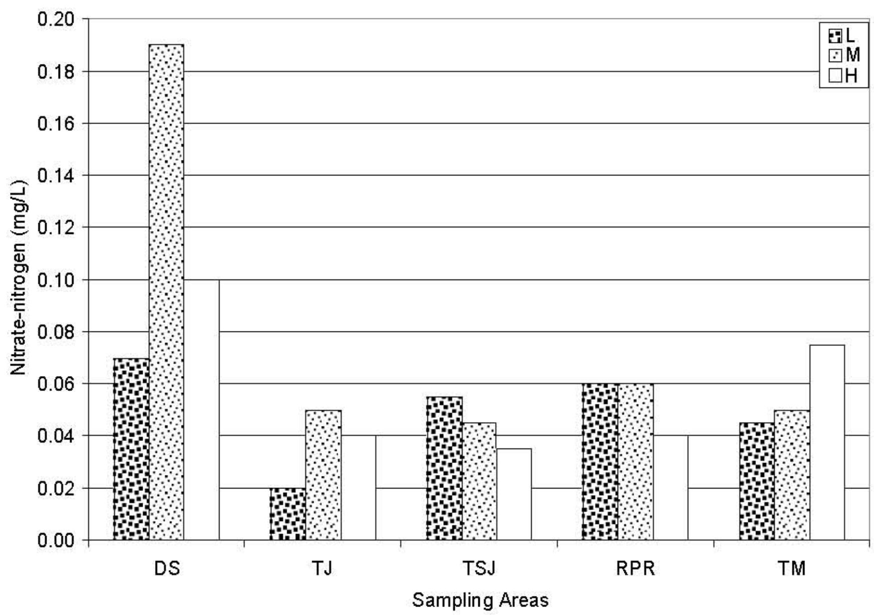

Fig. 4: Nitrate-nitrogen concentrations of wastewater from the five residential areas during low (L), medium (M) and high (H) flow.

BOD_5: BOD_5 concentrations were between 60-120 mg/L and the highest occurred during medium flow except for DS (Fig. 3). There is an opposite trend of concentrations of BOD_5 compared with DO in the five areas where high BOD_5 corresponded to low DO as more DO was consumed in oxidation of higher organic matter. During high flow, BOD_5 concentration was not as high as in medium flow due to dilution. BOD_5 concentrations and loadings (Table 2) were the lowest at DS. Analysis indicated that loading at DS is significantly lower than other areas (P= 0.005) and that in TM was significantly higher than other areas (P= 0.01). This could be due to the difference in sewerage system in DS as compared to other areas whereby in DS, effluent from sedimentation tank received treatment in the rock filter bed before discharge. Compared with BOD_5 reported in the pilot study [5], BOD_5 in the present study is between that reported for detached house (43 mg/L) and semi-detached (159 mg/L) but much lower than the terrace house (333 mg/L). The loading at DS was slightly higher than that of detached house (6,900 mg/c/d) and those at TJ, TSJ and RPR were slight lower than that reported for semi-detached house (12,600 mg/L) of the pilot study [4]. One-third of the BOD_5 concentrations from the residential areas were found to be within the range of 110-400 mg/L whereas the rest were lower [7]. The BOD_5 of untreated wastewater was reported to be 492-527 mg/L [1]. The low BOD_5 values in the present studies could be due to the partial treatment provided by individual septic tank and Imhoff tank. In addition, probably residents practised cleantech cooking, that is, food waste was not flushed into the drain but discarded into the rubbish bin. However, in all areas studied, BOD_5 exceeded the standard B BOD of 50 mg/l of the Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979.

Nitrate-nitrogen: Regardless of flow rate, the highest nitrate-nitrogen concentration (Fig. 4) and highest loading (Table 2) was found in DS. At DS, the highest concentration of nitrate was found during medium flow which corresponds to the lowest DO (Fig. 2). This is most likely due to the oxidation of ammonia to nitrate at the rock filter bed during nitrification where *Nitrosomonas* bacteria oxidized ammonia to nitrite and *Nitrobacter* bacteria further oxidized nitrite to nitrate. But for the septic tank system of the other areas, there was no rock filter bed for such treatment and DO in the septic tank was very low for nitrate formation. Thus, the nitrate concentrations were observed to be below 0.1 mg/L. In TM, the highest nitrate was during high flow where there was high washing and laundry. Similar observation was reported in Malta and England where the highest nitrate concentration was contributed by washing machine [1].

Reactive Phosphorus: For reactive phosphorus, in all areas, the highest concentration occurred in low flow wastewater (Fig. 5). This could be due to urine and faeces which are high contributors of phosphate. It was reported that 60% of phosphorus was contributed by urine in the absence of phosphorus detergents [13]. Furthermore, WC was reported to contribute 22% of the total household ortho-phosphorus in western countries [1]. Except for RPR, high flow has higher concentration than medium flow. This is most likely due to detergent used for washing and laundry. It was reported that the main contribution of phosphate in the receiving waters was detergent since one of the basic compounds in detergent, a builder, is generally a phosphate [13]. The results of a study of contributions of different appliances indicated that wash basin and washing machines are main contributors of ortho-phosphorus (27% and 37% respectively) [1]. The concentrations of reactive phosphorus in this study falls in the range of 4-13 mg/L for wastewater [7] but lower than that in England (14 mg/L) and Malta (15 mg/L) [1]. The phosphorus loading of the low cost areas was 1.6 times that of medium cost areas (Table 2). This could be due to more washing and laundry being carried out and possibly more liberal use of detergent. The mean phosphorus loads of 557-1020 mg/c/d are also lower than combined load of 1421 mg/c/d from different appliances [1].

E. coli: Table 3 shows the *E. coli* concentrations during high, medium and low flow of the residential areas studied. Regardless of the flow, *E. coli* concentrations were in the order of 10^6-10^7 CFU/100 mL. Loading of *E. coli* was the lowest in DS and significantly different from TSJ, RPR and TM (Table 2). This is likely due to the difference in the treatment system in DS whereby adsorption of *E. coli* onto the rock filter surfaces and further sedimentation and die-off of *E. coli* occurred in the rock filter bed. Furthermore, there could be overflowing of aged septic tanks in other areas as they had not been desludged. DS was relatively very new and also consists of lower population. The concentrations of *E. coli* were much higher than the standards stipulated under the Malaysian Interim Water Quality Standard (INWQS) of 5000 counts/100ml for Class IV. Mitchel and Yankofsky [15] suggested that intestinal microorganisms usually dieoff rapidly when discharged to water systems but

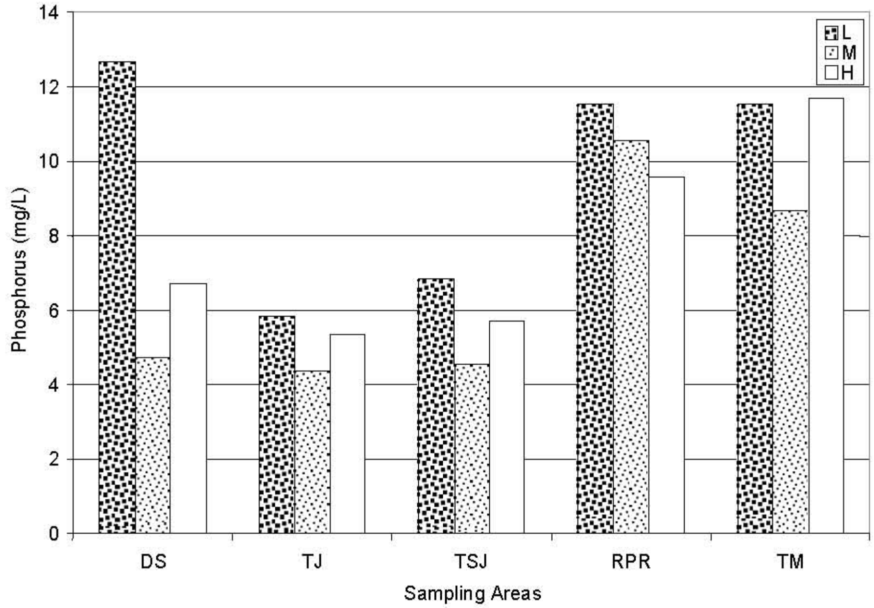

Fig. 5: Phosphorus concentrations of wastewater from the five residential areas during low (L), medium (M) and high (H) flow

Table 4: Total daily water consumption, wastewater production and pollutants loading from key residential areas in Kuching

	DS	Zone A	Zone B	RPR	TM	Total
Population	392	14,250	21,500	5,500	2,874	44,516
Water consumption (m^3/day)	75	3,770	3,859	1,570	1,066	10,340
Wastewater production (m^3/day)	41(16-58)	1,615(1101-2320)	2,577(1443-3842)	524(258-694)	349(213-468)	5,106(3031-7382)
BOD_5 (kg/d)	3.1(1.1-4.2)	165.8(94.0-240.1)	240.8(142.2-380.9)	59.8(27.1-80.6)	41.2(23.9-54.6)	511(288-760)
Phosphate-P (kg/d)	0.3(0.2-0.5)	8.2(6.2-12.0)	13.9(11.3-18.8)	5.6(3.0-7.3)	2.9(2.8-3.1)	31(23-42)
Nitrate-N (g/d)	3.8(3.1-4.8)	60.7(25.7-85.1)	117.8(55.3-192.1)	27.8(14.7-36.2)	19.7(10.6-31.7)	230(109-350)
E. coli (CFU/d) x10^{12}	1.3(0.4-2.6)	59.8(41.8-89.1)	60.9(47.5-79.4)	36.7(17.9-53.5)	20.1(8.9-27)	182(116-252)

** Zone A and Zone B are census zones which Tabuan Jaya and Taman Satria Jaya falls into respectively.*

Hendricks [16] showed that indicator organisms did indeed grow in natural systems. McFeters and Stuart [17] reported that the best survival of *E. coli* was between pH of 5.5 and 7.5. With the abundance of organic matter and favorable pH, *E. coli* might have survived and/or regrown in the sewerage systems or in the sediment of the storm drains. Generally, the septic tank ensures the hydraulic settling of solid matter as well as having a biological function in liquefying organic matter by methanogenic fermentation [18].

Total pollutants loading: Based on the populations of DS, the two census zones (A and B), RPR and TM, estimates of water consumption, wastewater production, loadings of BOD_5, reactive phosphorus and nitrate-nitrogen are shown in Table 4. With a total population of 44,516 from the areas studied, on a daily basis, 10 million liters of water was consumed, 5 millions liters of wastewater was produced contributing to 511 kg of BOD_5, 31 kg of reactive phosphorus, 230 g of nitrate-nitrogen and $1.84x10^{14}$ *E. coli* to surface water around Kuching. Undoubtedly the receiving waters in Kuching, the Sarawak River and its tributaries, are polluted with organic matter, nutrients and contaminated by faecal bacteria.

Conclusions and Recommendations: The production of wastewater was less than the water consumed. Reactive phosphorus was high and DO was low and not suitable for aquatic animals. There is an indication that septic tank played an important role in reducing organic matter but not so for *E. coli* reduction. *E. coli* concentrations and loading were high at all the residential areas. Imhoff tank at DS condominium provided further treatments resulting in significantly lower loadings of organic matter and higher nitrate-nitrogen. However, BOD_5 of wastewater discharged at all areas studied exceeded the sewage effluents standard. Low income residential areas produced significantly higher reactive phosphorus which is attributable to more usage of phosphorus detergents. Therefore, reduction of household pollutants or treatment of septic tank and Imhoff tank effluent is essential for the protection of water resources.

In the long run, pollution control at source and recycling of the nutrients should be emphasized to protect the receiving water from pollutants [19]. To reduce the volume of water consumed, low-flow model of toilet flushing system should be introduced. Compost toilets could replace the current high water consuming toilets [3]. Kitchen solid waste could be composed and used as fertilizers. The resulting wastewater which is very much reduced in volume could be treated by constructed wetland as it is becoming increasingly popular for wastewater treatment worldwide due to its low cost in construction and maintenance in addition to its use of natural processes in pollutants removal [20]. Excessive use of detergent should also be discouraged.

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