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CHARACTERIZATION OF WASTEWATER FOR SMALL SITES

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ABSTRACT
In order to design efficient wastewater treatment systems for institutional and residential sites, the study of the quantity and quality of wastewater for these sites is necessary. Accurate and site-specific data is necessary to design effective wastewater treatment systems for these sites. As for wastewater generation, studies on generation patterns from domestic sources are well-established. However, information on wastewater generation from institutional sources is still insufficient in Malaysia. This study focuses on wastewater generation patterns from several hospitals, schools and institutions of higher learning in Miri, Sarawak, including Curtin University of Technology Sarawak Campus. To study the wastewater generation patterns, the main assumption is that the volume of water consumed is equal to the volume of wastewater generated. Therefore, water meter readings indicating consumption of water at the study sites were retrieved at regular intervals, and plotted against time to obtain the wastewater generation pattern. Consistent with previous studies, the results showed that the wastewater generation patterns were directly related to the population size, and activities carried out on the study sites. To investigate the concentration of wastewater at the study sites, sampling of the wastewater was carried out. Water quality parameters such as dissolved oxygen, 5-day Biochemical Oxygen Demand (BOD_5), ammonia nitrogen, nitrate, orthophosphate, chlorine, pH and temperature were analysed. Low concentrations of pollutants were discharged from these sources. Also, the effectiveness of the Intermittently Decanted Extended Aeration (IDEA) Activated Sludge Wastewater Treatment System which is currently being utilised by Curtin University of Technology Sarawak campus was evaluated and the pollutant load was checked against its design capacity. The concentration of BOD_5 of the influent and effluent is 127.8mg/L and 7.5mg/L respectively, which satisfies both the design capacity of the IDEA treatment system and the Effluent Standard established by the Department of Environment, Malaysia (DOE). The research data collected from this study will be useful for the design of cost effective wastewater treatment systems for small, institutional sites.

Keywords: *wastewater generation, wastewater treatment, institutional wastewater, wastewater constituents*

INTRODUCTION
Malaysia generates about 6 million tonnes of sewerage each year [1]. Rapid population growth, expansion of cities and industrial development has contributed to a large amount of domestic and industrial wastewater. However, many of the current wastewater treatment plants in Malaysia are underperforming and overloaded. These over laden wastewater treatment plants are therefore not efficient and are unable to produce treated effluents that could meet the Malaysian discharge quality [1]. The untreated wastewater and storm water causes environmental contamination by escalating pollutant loads in the receiving water bodies that adversely affects the ecosystem and public health.

The Department of Environment (DOE) has researched the composition of water pollution sources in Malaysia in 2005 [2]. It was found that in Malaysia, 18,724 water pollution point sources composed mainly of sewage treatment plants (8,782: 46.9% inclusive of 562 Network Pump Stations), manufacturing industries (8,562: 45.7 %), animal farms (898: 4.8%) and agro-based industries (482: 2.6%). It can be observed that the water pollution is mainly caused by effluent of sewage treatment plants. In order to design effective wastewater treatment systems, the design capacity of the treatment plant needs to be determined from characteristics of the influent and effluent, in terms of quality and quantity of the wastewater and storm water. There are several factors that can influence the quantity and quality of domestic and institutional wastewater; such as function, location, popularity, characteristic of the residing family and business establishment, water-using fixtures and appliances [3].

Wastewaters generated from different development sites represent different wastewater generation patterns, flows and constituent. A practical study of the wastewater and storm water characteristics for domestic and institutional sources is necessary. At present, domestic wastewater generation information has been well established [7, 8] but studies on institutional and industrial wastewater and stormwater are still lacking in Malaysia. Characteristics of non-residential wastewaters therefore should be estimated based on available data from similar facilities [3]. Non-residential wastewater characterization criteria that can be easily applied and can accurately predict flows and pollutant loadings are available for only a few types of establishments [3]. In addition, they are difficult to develop and establish on a national basis with any degree of confidence [3]. Therefore, wastewater from existing establishments should be characterized by metering and sampling the current wastewater stream. For many existing developments and for almost any new development, however, characteristics of non-residential wastewaters should be estimated based on available data from similar facilities [3].

Due to contamination of natural water bodies with untreated wastewater and storm water, treatment, and adherence to the effluent standard before discharge into the water course is essential. Some of the common components that are usually analysed include biochemical oxygen demand (BOD), ammonia nitrogen nitrate, orthophosphate and free and total chlorine. This project focuses on institutional sources with the main area of study on wastewater and storm water generation patterns, as well as characterization and verification of wastewater and storm water constituents for small institutional sources in Miri. This research project also evaluates the efficiency of the Intermittently Decanted Extended Aeration (IDEA) Activated Sludge Wastewater treatment System currently in use in Curtin University of Technology Sarawak Campus.

METHODOLOGY

To study the wastewater generation patterns, it is assumed that the volume of water consumption is equal to the volume of wastewater generated. Hence, water meter readings were monitored and recorded to quantify water consumption and to produce the wastewater generation patterns for various sites, including primary schools, secondary schools, institute, hospitals and Curtin University of Technology, Sarawak Campus. All the research output were analyzed and discussed in this paper. In order to conduct this research, water meter readings from these study sites were recorded from 7 am to 7 pm daily with a time interval of 1 to 3 hours, for one week during each session. Several recording sessions during different seasons (eg. school holidays, tuition free weeks) were taken to account for different occupancy levels. The water meter readings for the duration from 7 pm to 7 am on the next day were obtained using interpolation.

Meanwhile, to determine the quality of the wastewater and storm water obtained from the study site, influent samples were collected from each institutional site and tested using the HACH surface waters test kits. In addition, BOD was tested as well. In this project, BOD test is conducted according to the Standard Method for the Examination of Water and Wastewater 5210: Biochemical Oxygen Demand. There are two methods used for BOD measurement: the dilution method (used here) and the manometric method. The dilution method is a standard method of the American Public Health Association (APHA) and is approved by the U.S. Environmental Protection Agency (UEPA) [2]. The obtained laboratory results were compared with the standard benchmark and the design capacity of the wastewater treatment plant.

RESULTS AND DISCUSSION

Wastewater Generation Patterns

Generally, wastewater flow rate is determined from the water consumption graph. In many international surveys, water consumption is used as an indicator of the wastewater generation as it is assumed that tap water, once used, will become wastewater and discharged to the wastewater systems [4]. Therefore in this project, such an assumption which indicates that the volume of water used is equal to the volume of wastewater discharged was employed. Water supply flow data is used to estimate the average daily wastewater discharges and it is agreed that 60 – 90% of the per capita water consumption becomes wastewater [5]. The characteristic patterns of wastewater flows have to be observed in terms of annual, seasonal, daily, hourly and sub-hourly time scales [6]. Figure 1 shows the typical hourly variation in water consumption for a medium-size city [7]. The water consumption during the winter season is observed to be different from the other seasons, and may influence the estimation of wastewater flow rates in such climates. Figure 2 presents the variation of the domestic wastewater flow rate during a day in a residential area [8]. The water consumption pattern for residential or domestic sources (Figure 1) is observed to be similar to the wastewater variation (or generation) flow pattern (Figure 2). This proves the validity of the main assumption of this study.

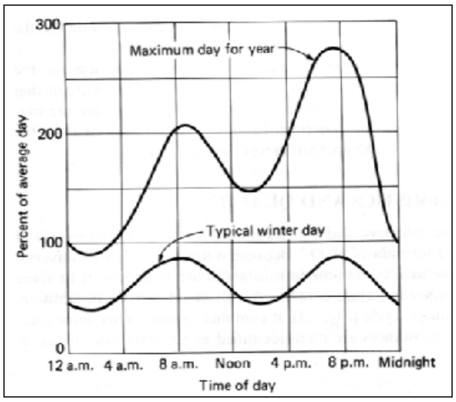


Figure 1: *Typical hourly variation in water consumption for a medium-size city [7]*

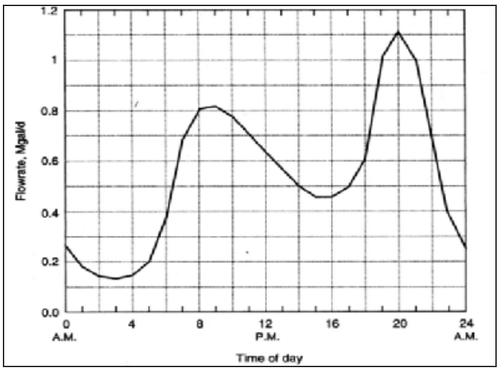


Figure 2: *Variation of the domestic wastewater flow rate during a day in a residential area [8]*

The wastewater generation pattern for towns and cities in Malaysia conform to these universal flow patterns as well [9]. In reference [9], a similar study was carried out earlier in several residential areas in Miri, Sarawak. Figure 3 shows a sample generation pattern for Krokop, a residential area in Miri. Water meter readings are plotted over a 7-day period. It is observed that the water generation pattern almost collapses into a single curve, and it conforms to the wastewater generation patterns shown in figures 1 and 2. Thus, it is reasonable to assume that these established, universal wastewater generation patterns would be applicable for households in Malaysia, based on Figure 3 and reference [9]. In Figures 1, 2 and 3, the main two peaks of curves shown in both figures occur in the late morning (7 am to 9 am) and in the early evening (6 pm to 8 pm) respectively. Thus, the main assumption as stated above is reasonable for estimating the wastewater flow rate and identifying the wastewater generation pattern.

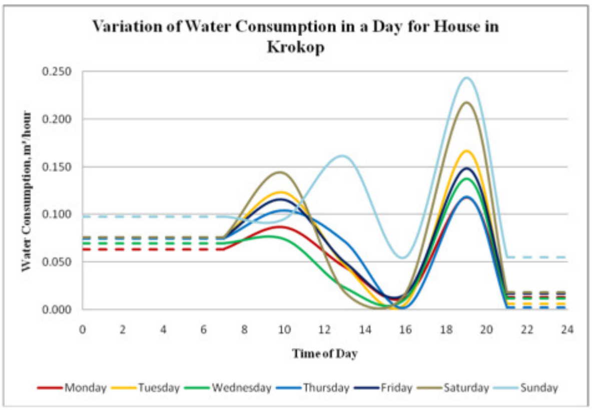
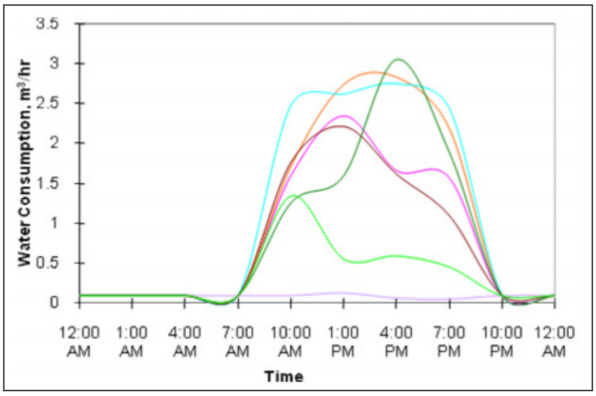


Figure 3: *Variation of water consumption in a day in Krokop, a residential area in Miri, Sarawak [9]*

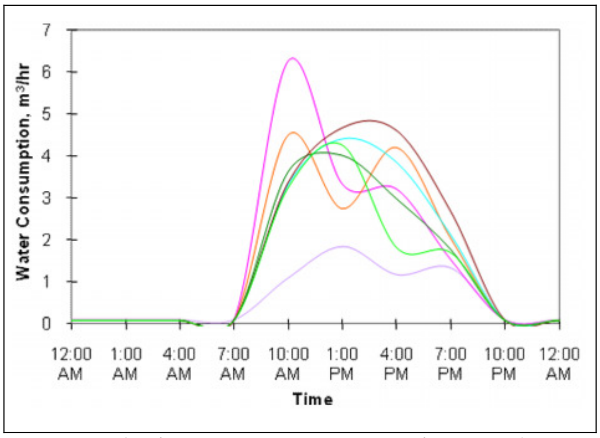
For this study, wastewater generation patterns of some organizations in Miri were chosen and studied, namely 2 primary schools (P1 and P2); 2 secondary schools (S1 and S2); 2 institutes or universities (X, and Curtin University of Technology Sarawak Campus); and 2 hospitals (A and B). Table.1 shows the area and population of those chosen institutional sources in Miri for this project such as area of sites and population.

Table.1: Area and population of the institutional sources in Miri

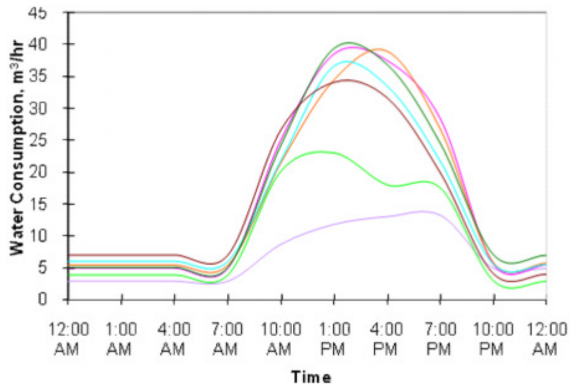
Institution		Area (ha)	Population	
Primary schools	P1	2.89	Students: 860	Staffs: 50
	P2	3	Students: 430	Staffs: 50
Secondary schools	S1	8	Students: 2500	Staffs: 135
	S2	8	Students: 450	Staffs: 45
Institute	X	8	Students: 1600	Staffs: 110
	Curtin		Students: 2500	Staffs: 150
Hospitals	Hospital A	-	Beds: 35	Staffs: 113
	Hospital B	-	Beds: 30	Staffs: 89



Example of Water Consumption Pattern for Primary School P1



Example of Water Consumption Pattern for Hospital A



Example of Water Consumption Pattern for Curtin University

For primary and secondary schools (Figure 4 for school P1), the hourly variation of water consumption patterns generally depict two peaks in a day. After investigation, it was revealed that the water consumption pattern was linked to the students' and staffs' schedules and activities that were being carried out in the schools. The two peaks which took place between 10 am to 12 noon and 3 pm to 5 pm occurred at the times of morning and afternoon break, as well as the student extracurricular activities which are conducted in the afternoon.

As for the hospitals (Figure 5 for Hospital A), the hourly variation of water consumption is irregular and has a fluctuating weekly wastewater generation pattern. There were typically two peaks in a day which happened to take place at different periods for different days. From observation, the water consumption patterns in hospitals are quite different from domestic water consumption (Figures 1, 2 and 3). Also, from the results obtained, the diurnal pattern with hourly variation of water usage during tuition free week and during teaching week for Curtin University of Technology (Figure 6) differs from the typical domestic water consumption patterns, and corresponds to previous studies [10]. There is only one peak in a day which generally occurs between 12 noon to 2 pm which is during the lunch time for students and staffs. On the whole, the diurnal pattern for the institutional water consumption is different from that of the domestic's. The variation is strongly dependent on function, location, popularity, characteristic of residing family and business establishment, activities, water-using fixtures and appliances.

Estimation of Wastewater Flows

According to the Malaysian Sewerage Code of Practice, it can be assumed for sewage design purposes that a single resident within a Catchment Area generates an average daily sewage flow of 225 litres per day [11].

Average Dry Weather Flow (ADWF) is the sewage flows that are generated at source and discharged directly into sewers without mixing with any other form of liquid flow, such as groundwater or storm water [11].

$$\text{ADWF} = \text{Total PE Count} \times 225 \text{ litres/day} \tag{1}$$

Peak Wet Weather Flow (PWWF) is the estimated ADWFs multiply by a derived Peak Flow Factor (PFF). The equation shows as below:

$$\text{PWWF} = \text{Peak Flow Factor} \times \text{ADWF} \tag{2}$$

In Malaysia, an empirical equation for peak flow factor, which takes into account the presence of extraneous flow in the system, is recommended as below [12]. Population equivalent (PE) is the design parameter and is converted to a flow rate.

$$\text{Peak Flow Factor, PFF} = \frac{4.7}{\left(PE/1000\right)^{0.11}} \tag{3}$$

Table 2. Comparisons of practical water consumption and theoretical wastewater flows

Institution		Observed maximum water consumption (m^3/day)	Estimated ADWF (m^3/day)	Estimated PWWF (m^3/day)
Primary schools	P1	10.9	38.7	220.7
	P2	23	19.4	119.1
Secondary schools	S1	23.8	112.5	570.6
	S2	5.6	20.3	124.0
Institute	X	33	72.0	383.6
University	Curtin	160	112.5	570.6
Hospitals	Hospital A	16	31.5	183.8
	Hospital B	34	27.0	160.2

From Table 2, the estimated peak wet weather flows (PWWF) for different institutional sites were compared with the observed and recorded maximum flows of water consumption which were obtained by monitoring water meter readings. It is observed that the values of PWWFs are significantly higher than the observed flow of maximum water consumption. The possible reason for this is that the observed water consumption does not take into account the occurrence of extraneous flows, such as infiltration and inflows. Extraneous flows are considered in the calculation of PWWFs by multiplying peak flow factor (PFF).

Design of sewer pipelines and wastewater treatment system by means of conservation and convenience is according to the PWWF values which show the estimated maximum possible flow rates. From the comparison, if only sewage flow is considered, and extraneous flow is ignored, the design capacity of sewer collection system is capable of catering to the sewage flow. PWWF gives a very conservative design value to the sewage flow rate.

Wastewater and Storm water Constituents

The constituents of wastewater generated from 3 institutional establishments in Miri, namely School S2; Institute X; and Curtin University of Technology, Sarawak Campus were investigated and presented here.
The obtained laboratory results for School S2 and Institute X were compared with the typical concentration of domestic wastewater which is presented in Table 3. The quality of influent and effluent for the IDEA treatment system in Curtin University Sarawak Campus were compared to its design capacity which is tabulated in Table 4. The constituent test results of the institutional wastewater samples are presented in Table 5.

Table 3.Typical composition of untreated domestic wastewater [7]

Contaminants	**Concentration (mg/L)**		
	Weak	**Medium**	**Strong**
Solid, total (TS)	350	720	1200
Dissolved, total (TDS)	250	500	850
Fixed	145	300	525
Volatile	105	200	325
Suspended solids (SS)	100	220	350
Fixed	20	55	75
Volatile	80	165	275
Settleable solids	5	10	20
Biochemical oxygen demand, 5-days (BOD_5, 20°C)	110	220	400
Total organic carbon (TOC)	80	160	290
Chemical oxygen demand (COD)	250	500	1000
Nitrogen (total as N)	20	40	85
Organic	8	15	35
Free ammonia	12	25	50
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	4	8	15
Organic	1	3	5
Inorganic	3	5	10
Chlorides	30	50	100
Sulfate	20	30	50
Alkalinity (as $CaCO_3$)	50	100	200
Grease	50	100	150

Table 4. Design capacity of idea treatment plant in Curtin University of Technology, Sarawak campus [13]

Parameter	Design capacity		
Population equivalent	1,800 persons		
Average sewage flow	405 m^3/day		
Peak sewage flow	1782 m^3/day		
BOD_5 loading	101.25 kg/day		
	Influent	Effluent	Effluent Standard A
BOD_5	250 mg/L	10 mg/L	20 mg/L
SS	300 mg/L	20 mg/L	50 mg/L
pH	-	-	5.5 to 9.0

Table 5. Wastewater composition for school S2, institute x and Curtin University Sarawak campus

Establishment	School S2	Institute X	Curtin University	
Type of sample	Raw greywater		Influent	Effluent
Contaminant	Concentration			
Temperature (°C)	30.3	30.6	27°C	29°C
pH	8.8	7.8	8.2	8.2
DO (mg/L)	0.90	2.51	0.21	3.16
BOD_5 (mg/L)	75.8	43.6	127.8	7.5
NH_3-N (mg/L)	> 5	> 5	> 5	> 5
NH_3 (mg/L)	> 1.68	> 0.24	> 0.47	> 0.53
NH_4^+ (mg/L)	> 3.32	> 4.76	> 4.53	> 4.47
NO_3-N (mg/L)	0	0	0	0
NO_3 (mg/L)	0	0	0	0
Total chlorine (mg/L)	0	0	0	0
Free chlorine (mg/L)	0	0	0	0
PO_4^{-2} (mg/L)	2.50	3.10	12.00	6.00
P (mg/L)	0.83	1.03	4.00	2.00

School S2 and Institute X

Secondary school S2 has 450 students and 45 staff members. Whereas institute X is a government higher education establishment in Miri that has 650 students and 140 staff members. Septic tanks are used to treat black water in both school S2 and institute X. The wastewater samples collected from these 2 study sites contained untreated grey water and storm water, which do not entail the effluents from the septic tanks. In Malaysia, the only established standard in the relevant field is the Effluent Quality Standard with no indication of appropriate standard for raw wastewater quality. Therefore, pollutant strength of the samples collected from secondary S2 and institute X which consist of untreated raw grey water was evaluated using the typical constituent concentration of untreated domestic wastewater as reported in Table 3. By comparison, the wastewater for both the organizations was classified under the weak concentration category. Thus, the wastewater discharged from these two educational facilities has weak pollutant loads due to low concentration of constituents with reference to the values given in Table 3 which is for typical domestic wastewater.

Curtin University of Technology, Sarawak Campus

The Intermittently Decanted Extended Aeration (IDEA) Activated Sludge Wastewater Treatment System is currently being used to treat all the wastewater, including blackwater and greywater generated from the main campus and the students' lakeside apartments in Curtin University's Sarawak Campus. From the experimental results shown in Table 5, it can be seen that the pollutant load of the effluent leaving the IDEA plant were significantly reduced after the treatment. Concentration of BOD_5 of the untreated influent was effectively reduced from 127.8mg/L to 7.5mg/L which is as much as 94%. Besides, the concentration of BOD_5 of the influent and effluent satisfies the design capacity of the treatment plant which is designed to cater for influent with maximum of 250mg/L BOD_5 and effluent with maximum of 10mg/L BOD_5 as shown in Table 4. After treatment, a 50% reduction in the concentration of phosphate and phosphorus was achieved, which was a decrease from 12mg/L to 6mg/L and 4mg/L to 2mg/L respectively. Since no disinfection method is used in treatment system, zero concentration of total and free chlorine was tested. Thus from this research, the effectiveness and soundness of the IDEA treatment system in Curtin University of technology, Sarawak campus at the current state is proven and verified to cater for the contemporary increasing population and campus extension.

CONCLUSIONS

In conclusion, it is shown that the wastewater generation patterns of institutional establishments are different from the ones generated by domestic sources. For the institutional establishments, the peak of wastewater disposal usually occurs at noon, while for domestic sources, the peak falls in the late morning and mid-evening periods. These patterns are directly in consequence with the different types of activities being carried out at these sites due to the different function that these premises serve. From this project, it is found that the population and the on-going activities significantly affect the wastewater generation patterns as well as its volume generated. The volume of wastewater generally increases proportionally with the increasing population. Institutional establishments like hospitals and schools are also subject to seasonal variation in their wastewater generation pattern, where occupancy rates vary with number of patients, or seasons such as term time and holidays. Thus, for studying wastewater generation patterns for similar small sites, it is important to consider seasonal as well as diurnal variation.

This study has also shown that the domestic wastewater generation patterns in Malaysia conform to the established, universal domestic wastewater generation patterns as shown in Figures 1 and 2. A representative wastewater generation pattern for Krokop, a residential area in Miri, Sarawak is shown in this paper. In terms of quality, the wastewater and storm water from secondary school S2 and institute X are categorized as weak pollutant strength. Individual septic tanks (IST) are currently used to treat black water in those sites whereas the untreated grey water is discharged directly into the drain. Although the sewage discharged from these sites contains weak pollutant load, a proper treatment system is suggested to be installed in order to generate better quality effluent for the interest of minimising environmental contamination and to ameliorate public health in Malaysia. The concentration of the pollutant constituents could vary significantly, according to seasonal variation as well as weather and other environmental conditions. This will be addressed in future studies. Evaluation of the design capacity and effluent of the IDEA treatment plant in Curtin University of Technology, Sarawak Campus finds that the system is efficient and is still fit for the continuously increasing campus size and population. Monitoring the quality of the influent and effluent of a treatment system is essential to check for necessary maintenance and upgrades to effectively treat the wastewater and storm water .

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REFERENCES

[1] Malaysian water sector (2006) Embassy of Denmark, Kuala Lumpur, http://www.ambkualalumpur.um.dk/NR/rdonlyres/4FC19871-2DBC-4096-9E47-D5D64EF1F182/0/MalaysianWaterSector.pdf (accessed: 25 March 2008)
[2] Department of Environment 2006, Malaysia Environment Quality Report 2005, Malaysia.
[3] United States Environmental Protection Agency (2002) Onsite wastewater treatment systems manual chapter 3: Establishing treatment system performance requirements. http://www.epa.gov/nrmrl/pubs/625r00008/html/625R00008chap3.htm (accessed: 12 May 2008)
[4] Larsen, Ib. & Lynghus, H. (2004) Framework Plan for Integrated Wastewater Management for the City of Kuching, Sarawak, Sarawak Government and DANIDA, Kuching.
[5] Metcalf and Eddy Inc (1991) Wastewater Engineering: Treatment, Disposal and Reuse, 3rd edn, McGraw – Hill, NY, USA.
[6] Butler, D., Friedler, E. & Gatt, K. (1995) Characterizing the quantity and quality of domestic wastewater inflows. Water Science and Technology, vol. 31, no. 7, pp. 13-23.
[7] Linsley, R. K., Franzini, J. B., Freyberg, D. L. & Tchobanoglous, G. (1992) Water Resource Engineering, 4th edn, McGraw-Hill.
[8] Crites, R. & Tchobanoglous, G. (1998) Small and decentralized wastewater management sytems, McGraw-Hill, United States of America.
[9] Wee, C.K. (2008) Domestic wastewater management in Sarawak and feasibility of oxidation pond as a treatment method. BEng Thesis, Curtin University of Technology Sarawak Campus.
[10] Tan, A.H. (2006) A study into a viable wastewater treatment system for a commercial site in Sarawak. BEng Thesis, Curtin University of Technology Sarawak Campus.
[11] Guidelines for Developers: Sewerage Policy for New Developments 1999, vol 1, 2nd edn, Sewerage Services Department, Ministry of Housing and Local Government, Kuala Lumpur.
[12] Standards & Industrial Research Institute of Malaysia 1991, Malaysian Standard Code of Practice for Design and Installation of Sewage Systems, MS 1228:1991
[13] Weida Environmental Technology Sdn.Bhd. n.d., Operation and Maintenance Manual: Intermittently Decanted Extended Aeration (IDEA) Activated Sludge Sewage Treatment Plant for Curtin University of Technology, Sarawak Campus, Miri, Sarawak, Kuching.