Journal of Science and Technology ***54*** *(2A) (2016) 265-272*

SEWER DISCHARGE CHARACTERISTICS AND WATER BALANCE IN DRY SEASON IN HUE, VIETNAM

Tran Nguyen Quynh Anh[1], Hidenori Harada[1,*], Shigeo Fujii[1], Pham Khac Lieu[2], Duong Van Hieu[2] and Shuhei Tanaka[1]

[1]*Graduate School of Global Environmental Studies, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, JAPAN*

[2]*Department of Environmental Science, Hue University of Sciences, 77 Nguyen Hue street, Hue city, Vietnam*

[*]Email: *harada.hidenori.8v@kyoto-u.ac.jp*

Received: 15 May 2016; Accepted for publication: 15 June 2016

ABSTRACT

Vietnam has been developing sewerage recently. Although sewer discharge quantity and quality data is vital for proper sewage management, their fluctuation has not been well characterized in most of cities in developing countries. This study aimed to characterize a combined sewer discharge in a residential drainage area (11.2 ha) in Hue city, Vietnam on dry days in dry season (DdDs). A 24-hour survey on sewage quantity and quality was conducted at the sewer outlet on two weekdays and two weekends in July 2015. Household water consumption was hourly recorded from water meters for 23 households. Then results of discharge characteristics were compared with those on dry days in rainy season (DdRs) of our previous study. Results showed that hourly variations of flow rate corresponded to the water consumption trend. Average discharge flow rate was equivalent to 38.5 ± 4.4 L/cap/day, which was much lower than that on DdRs (64.2 ± 25.0 L/cap/day). In contrast, pollutant concentrations on DdDs were higher than those on DdRs and fluctuated slightly in a day and among days in a week. Low concentrations of discharge in both dry season and rainy season showed that domestic wastewater in urban Hue was not strongly polluted in terms of organic matter and nutrients. Sewer water balance showed that only 29 % of total water inputted to the sewer system was discharged through the outlet on DdDs, while the remaining 71 % was likely exfiltrated to the ground from the sewer system, which will be a potential pollution source to soil and groundwater.

Keywords: combined sewer system, dry season, flow rate, sewer discharge, water balance.

1. INTRODUCTION

Recently, Vietnam has been developing sewerage systems. Good characterization of wastewater is critical for a successful design and operation of a sewerage system. One of the main characters of domestic wastewater is that its flow and composition are not steady or uniform, but vary throughout the time (hourly variation, daily variation, seasonal variation) [1]. These variations are very important information but have not been well characterized in most of cities in developing countries. This is one of the main reasons resulting in improper performance or failure of sewerage systems.

Hue city, located in the center of Vietnam, is a heritage city and an important tourism center of the country. Similar to many urban areas in Vietnam, Hue city is planned to develop the sewerage system in near future [2] to improve the city environment. Determining wastewater flow rates and constituent concentration is a fundamental step in the design of wastewater treatment facilities [3]. The characteristics of sewer discharge in a residential area in urban Hue city were characterized in our previous study in rainy season [4]. Due to the seasonal variations of wastewater, we continued our study to investigate the sewer discharge characteristics and their fluctuations in dry season to compare with those in rainy season in order to show a comprehensive picture of sewer discharge characteristics in urban Hue.

2. MATERIALS AND METHODS

2.1. Study area

The study area was a residential area in Thuan Thanh ward, Hue Citadel, Hue city, Vietnam (Figure 1). The area covered 11.2 ha, with the population of 1,452 distributed in 363 households in 2015 [5]. 100 % of households had access to tap water and average water consumption was 153.7 L/cap/day in 2015 [6]. All of households had flush toilets and 71 % of which connected to septic tanks [our survey]. Greywater and septic tank effluent were collected by a public combined sewer system or discharged to nearby water bodies or surface/underground. The sewer system in the study area was composed of 836 m open ditch; 1,992 m sewer and 124 manholes [7]. Sewer pipes were made of concrete and buried at 700 mm depth from the surface road. Wastewater after collected and transported in small size pipelines (400-800 mm in diameter) was eventually poured into the main pipeline (1000 mm in diameter) and discharged into Tinh Tam Lake through a single final outlet.

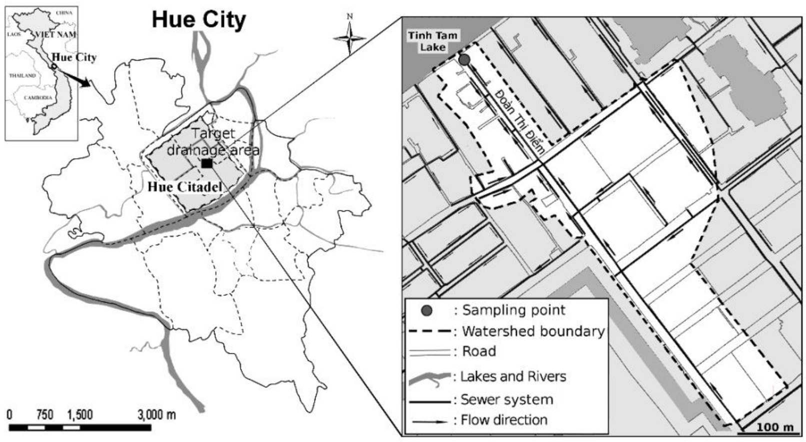

Figure 1. Target drainage area [7].

2.2. Sewer discharge survey

A 24-hour survey on sewage quantity and quality was conducted at the sewer outlet on two weekdays (22nd and 23rd, July) and two weekends (18th and 25th, July) in dry season in 2015. A 90° V-notch weir was used to measure the discharge flow rate. Head on the weir was recorded every hour during 24 hours of each day, and discharge flow rate was calculated using the Cone equation [8] as follows:

$$Q = 3600 \times 1.36 \times H^{2.48} \tag{1}$$

where Q is the discharge over the weir (m^3/h); H is the head of the weir (m).

One of the limitations in using V-Notch for measuring flow rate was that the V-Notch might impede the flow and affect the measured flow rate due to the accumulation of sewage. Therefore, a calibration of flow calculation was made by taking into accounts the stored water in sewer pipes with the consideration of sewer slope to estimate the actual flow rates.

Sewage samples were collected at the same time of flow rate discharge survey. SS and VSS were measured with 1-hour interval; COD_{Cr}, NH_4^+, TN and TP were measured with 2-hour interval; and BOD_5 with 4-hour interval (Table 1). All parameters were analyzed in particulate and dissolved phases separately by the Standard Methods [9].

Table 1. Description of sampling time and parameters analysis.

Time	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**1**
Flow rate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SS, VSS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
COD_{Cr}, NH_4^+, TN, TP	X		X		X		X		X		X		X		X		X		X		X		X		X
BOD_5	X				X				X				X				X				X				X

Pollution load from sewer discharge was calculated as follows:

$$L_i = \sum_{t=1}^{24} C_{i,t} \times Q_{i,t} \tag{2}$$

where L_i is the total load of parameter *i* (g/day); $C_{i,t}$ is the concentration of parameter *i* at time *t* (g/m^3); $Q_{i,t}$ is the corresponding discharge flow rate at time *t* (m^3/h).

2.3 Hourly water consumption survey

A water consumption survey was conducted on four days in July 2015 (the same days with sewer discharge survey) to investigate the hourly variation of water consumption. Water consumption amounts were recorded hourly during 24 hours of each day based on a water meter of each household. In total 23 water meters were accessed for recording.

2.4 Water balance calculation

A water balance was calculated for the drainage area on dry days in dry season and rainy season based on **Eq. 3**:

$$GW + SE \pm IF/EF = Q \tag{3}$$

where *GW* is the total household greywater amount discharged into the sewer system (L/cap/day); *SE* is the total septic tank effluent amount discharged into the sewer system (L/cap/day); *IF/EF* is the water infiltration to or exfiltration from the sewer system (L/cap/day); and *Q* is the sewage amount discharged at the final outlet of the sewer system (L/cap/day).

Household greywater *(GW)* and septic tank effluent *(SE)* discharge amount were calculated based on Eq. 4 and Eq. 5:

$$GW = Q_{GW} \times r_{GW} \tag{4}$$

$$SE = Q_{SE} \times r_{SE} \tag{5}$$

where Q_{GW} and Q_{SE} are the amounts of greywater and septic tank effluent generated from households (L/cap/day); r_{GW} and r_{SE} are the ratios of household discharged their greywater and septic tank effluent into sewer system, respectively.

Q_{GW} and Q_{SE} were estimated as 80 % and 20 % of total water consumption amount of the drainage area in 2015 (153.7 L/cap/day) [6].

Values of r_{GW} *and* r_{SE} (0.96 and 0.53, respectively) were obtained from our survey on wastewater management for 100 households in the drainage area.

Water infiltration or exfiltration amount *(IF/EF)* was estimated by mass conservation law.

3. RESULTS AND DISCUSSION

3.1 Sewer discharge flow rate and water balance in the sewer system on dry days in dry season

Hourly variations of discharge flow rate on dry days in dry season (DdDs) are presented in Figure 2-a. Two peaks of discharge were observed from 6:00 – 17:00 and from 17:00 – 24:00. The lowest discharges were observed during the early morning (1:00 – 6:00). The fluctuation of discharge flow rate basically corresponded to the water consumption trend (Figure 2-b) although distinct peaks in the morning, lunch time and evening were not obviously observed. The hourly variations of discharge flow rates in study area were rather similar to the pattern of typical hourly variations of domestic wastewater flow rates described by Tchobanoglous *et al.* [3].

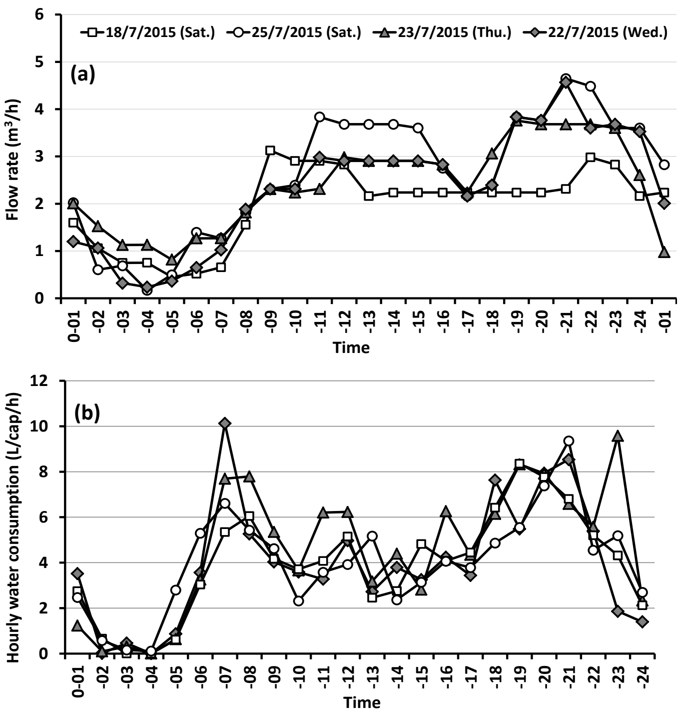

Figure 2. Hourly sewer discharge flow rate on dry days in dry season (a) and hourly water consumption of 23 households living in the target drainage area (b).

The average discharge flow rate on DdDs was 2.33±0.27 m^3/h (ave.±s.d.) (equivalent to 38.5±4.4 L/cap/day). It was lower than that on dry days in rainy season (DdRs) (4.5±1.8 m^3/h or 64.2±25.0 L/cap/day) in our previous study [4], which reflected the seasonal variation of discharge. There was no significant difference in discharge flow rate between weekdays and weekends ($P>0.05$). Discharge flow rate on DdDs only accounted for 29 % of the total water inputted the sewer system (Figure 3-a). This means a very large portion of sewage (71 %) did not reach the outlet and might exfiltrate into the ground. On DdRs, the exfiltrated water was lower than that on DdDs but still rather high (44 %) (Figure 3-b). The leakage ratio of wastewater from sewer systems varied greatly among areas (accounted for 1 % - 56 % of total dry weather flow) [10]. Age of sewer system was considered as the most significant factors governing the sewer leakage [11]. The high leakage ratio in our study area might be due to the sewer system in Hue city was rather old and poorly maintained (from the 1880s – in the French colonial period [7]). This situation should be paid attention since the leakage wastewater potentially contaminated soil and groundwater in the area. However, the leakage wastewater amount in this study was estimated indirectly by a water balance. A further study focusing on sewer leakage should be conducted in the future.

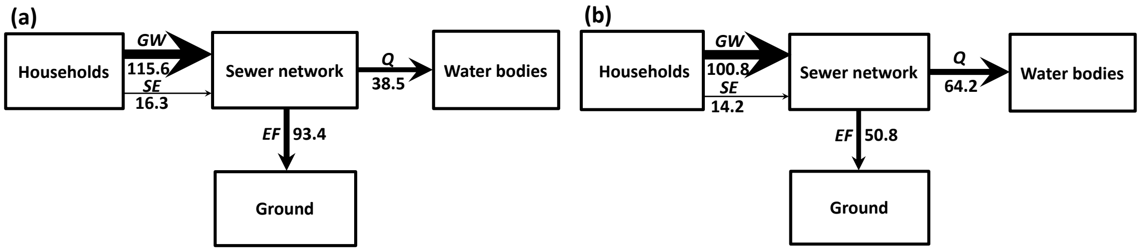

Figure 3. Water balance in a combined sewer system on average dry days in dry season 2015 (n=4) (a) and average dry days in rainy season 2014 (n=5) (L/cap/day) (b).

3.2 Sewer discharge quality in dry season

Sewer discharge concentration patterns of SS, COD_{Cr}, TN and TP are showed in Figure 4 as representatives. The discharge concentrations did not show strong fluctuation among hours in a day and among days in a week, especially particulate concentrations. Concentrations of discharge on DdDs were slightly higher than those on DdRs [4] (Table 2). Low concentration of sewer discharge on dry days in both seasons showed that domestic wastewater in Hue city was not strongly polluted. Sewer discharge concentrations in urban Hue were rather similar to the influent concentrations at a wastewater treatment plant in Hanoi [12], but were much lower than those in other areas in Asia (Table 2). Higher concentration of dissolved phase than particulate

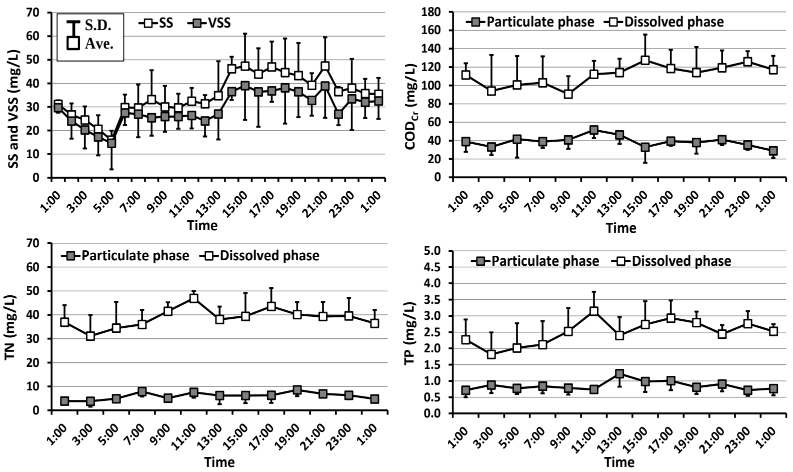

Figure 4. Sewer discharge concentration pattern at the outlet in dissolved and particulate phase.

phase (Table 2) showed that the discharge from outlet was mainly dissolved matter. The dominant of dissolved matter compared to particulate matter was indicated in wastewater at source [13]. Moreover, in-sewer settling processes due to low velocity of flow and the impact of V-Notch might reduce the particulate matter discharged at the outlet. To reflect more accurately the ratio of particulate and dissolved matter discharged, it is suggested to conduct the discharge quality survey at a different time or site with the flow rate survey.

Table 2. Wastewater concentrations at the outlet on dry days in dry season in compared with those in rainy season and those in the influent at WWTPs in other areas.

Item		At sewer outlet		At wastewater treatment plants (influent)				
		Hue - Dry season (This study)	Hue - Rainy season (Previous study)[4]	Hanoi - Dry season [12]	Hanoi - Rainy season [12]	Malaysia[14]	Bangkok[15]	Low strength[3]
SS	(mg/L)	37.5 ± 5.1	21.6 ± 0.6	46	45	124	60	120
VSS	(mg/L)	31.3 ± 4.6	16.1 ± 3.1	---	---	---	---	95
COD_{Cr}	(mg/L)	154.2 ± 15.7 (74.5%)	69.7 ± 3.2 (63.8%)	118	109	294	---	250
BOD_5	(mg/L)	92.9 ± 15.9 (82.5%)	25.2 ± 3.9 (61.1%)	47	40	135	44	110
TP	(mg/L)	3.5 ± 0.4 (75.3%)	2.1 ± 0.3 (71.4%)	9.7	7.2	7	2.2	4
PO_4^{3-}	(mg/L)	---	1.8 ± 0.3 (83.3%)	---	---	---	---	---
TN	(mg/L)	46.1 ± 4.8 (86.2%)	23.1 ± 0.0 (87.4%)	43	31	53	11	20
NH_4^+	(mg/L)	31.7 ± 5.1 (87.9%)	20.1 ± 0.2 (95.5%)	40	27	---	---	12

Note:
(1) Percentage of dissolved concentration is provided in parenthesis
(2) Number of sample in Hue - Dry days in dry season:
- SS, VSS: 1 hour-interval sample during 24 hours of each day in 4 days
- COD_{Cr}, TP, NH_4^+, TN: 2 hour-interval sample during 24 hours of each day in 4 days
- BOD_5: 4 hour-interval sample during 24 hours of each day in 4 days

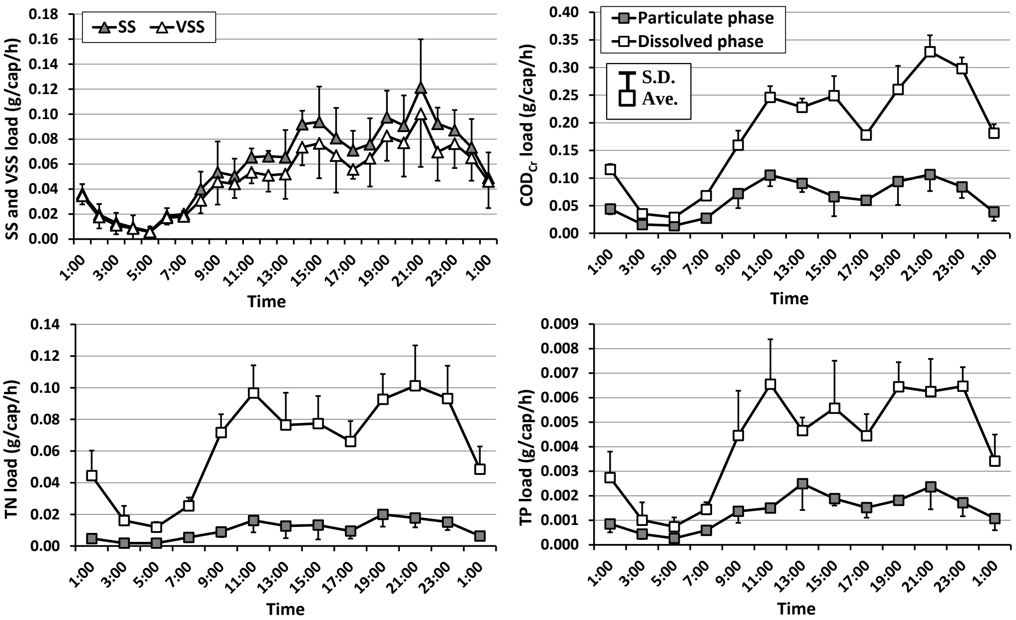

Figure 5. Pollution loads at the sewer outlet on dry days in dry season 2015.

Pollution loads at the outlet showed the same pattern for all items (Figure 5). There were two peaks of discharge (7:00 – 17:00 and 17:00 – 1:00). The lowest discharges were observed during the early morning time (1:00 – 7:00). Unit pollution loads of SS, VSS, COD_{Cr}, BOD_5, TN, NH_4^+, TP on DdDs were 1.43 ± 0.12 g/cap/day, 1.19±0.14 g/cap/day, 5.88±0.44 g/cap/day, 3.39±0.30 g/cap/day, 1.76 ± 0.20 g/cap/day, 1.20±0.06 g/cap/day, and 0.13±0.00 g/cap/day, respectively. These results were slightly lower than the unit loads on DdRs (SS: 2.06±0.11 g/cap/day, VSS: 1.44 ± 0.60 g/cap/day, COD_{Cr}: 6.11±1.79 g/cap/day, BOD_5: 2.25±0.91 g/cap/day, TN: 2.00±0.46 g/cap/day, NH_4^+: 1.74±0.38 g/cap/day, TP: 0.18±0.02 g/cap/day) and many times lower than those in other areas such as Iran [16], Brazil, Denmark, Japan [3]. This remarkable difference might be explained by the difference in living situation among the countries, but also might be due to in-sewer processes such as sewer leakage, the particle settling due to low velocity in study area. Therefore, it is suggested that in-sewer processes, especially sewer leakage and settling process should be examined in a further study.

4. CONCLUSIONS

Combined sewer discharge characteristics in an urban residential area in Hue city on dry days in dry season (DdDs) were presented and compared with those on dry days in rainy season (DdRs). Discharge flow rate on DdDs fluctuated among hours in a day and corresponded to the water consumption trend. Average discharge flow rate on DdDs was 2.33±0.27 m^3/h, which was lower than that on DdRs (4.5±1.8 m^3/h). There was no significant difference on discharge flow rate between weekdays and weekends. Discharge flow rate at the outlet only accounted for 29 % of total water inputted to the sewer system. This indicated that a great amount of sewage exfiltrated into the ground and might contaminate soil and ground water. Discharge concentrations on DdDs were slightly higher than those on DdRs. Low concentrations of discharge in both dry and rainy season showed that domestic wastewater in Hue was not strongly polluted. This is probably a characteristic of domestic wastewater in urban areas in Vietnam since the wastewater quality in Hanoi was also at a similar level. A remarkable difference among unit pollution loads from sewer systems in study area and other countries suggested that in-sewer processes, especially sewage leakage and settling process should be studied more detail.

Acknowledgements. The study was partially funded by KAKENHI (16H02748). The authors wish to express gratitude to students of Environmental Science Department for their kindly support during the survey.

REFERENCES

1. Von Sperling M. – Wastewater characteristics, treatment and disposal, Volume 1, Biological treatment series, IWA, London, UK, 2007, p.304.
2. Hue city Portal, http://huecity.gov.vn/?cat_id=296&optionid=0&id=8413, accessed on February 15, 2016.
3. Tchobanoglous G., Burton F. L., and Stensel H. D. – Wastewater engineering: treatment and reuse, Metcalf & Eddy, 4th ed., McGraw-Hill, New York, USA, 2004, p.186.
4. Anh T. N. Q., Harada H., Fujii S., Anh P. N., Lieu P. K, and Tanaka S. – Characterization of combined sewer discharge in Hue city, Vietnam, Journal of Science and Technology **53** (3A) (2015) 187-192.

5. People's Committee of Thuan Thanh ward – Population data of Thuan Thanh ward, unpublished data, Thua Thien Hue Province, Vietnam, 2015.
6. Thua Thien Hue Construction and Water Supply State-owned Company Limited (HUEWACO) – Data on tap water supply in Hue city in June & July 2015, unpublished data, Thua Thien Hue Province, Vietnam, 2015.
7. Hue Urban Environment and Public Works State Limited Company (HEPCO) - Drainage system in Hue city, unpublished data, Thua Thien Hue Province, Vietnam, 2013.
8. U.S. Department of the Interior, Bureau of Reclamation (USBR) – Water Measurement Manual, 3rd edition, Washington DC, USA, 1997, p.317.
9. APHA, AWWA, and WEF – Standard Methods for the Examination of Water and Wastewater, 21st edition, Washington DC., USA, 2005, pp.1070-1072.
10. Rutsch M., Rieckermann J., Cullmann J., Ellis J. B., Vollertsen J., and Krebs P. – Towards a better understanding of sewer exfiltration, Water Research **42** (2008) 2385-2394.
11. Bishop P. K., Misstear B. D., White M., and Harding N. J. – Impact of sewer on groundwater quality, Journal of the Chartered Institution of Water and Environmental Management **12** (3) (1998) 216-223.
12. Nga T. T. V., Canh V. D., and Zuber P. A. – Wastewater characterization and its impacts to the performance of water treatment plant in Hanoi City, Vietnam, the 11th International Symposium on Southeast Asian Water Environment, Bangkok, Thailand, 2014, p.17.
13. Anh P. N, Fujii S., Harada H., Tanaka S., Lien N. P. H., and Hai H. T. – Study on household pollution loading and evaluation of septic tanks' function, USB proceeding of the 13th IWA WRBM Conference, San Francisco, USA, 2014, p.8.
14. Kling S. – Determination of domestic wastewater characteristics and its relation to the type and size of developments, Master thesis, Faculty of Civil Engineering, Universiti Teknologi, Malaysia, 2007, p.57.
15. Department of Drainage and Sewerage – Water quality analysis of water environment control plant, Bangkok, Thailand, 2010.
16. Mesdaghinia A., Nasseri S., Mahvi A. H., Tashauoei H. R., and Hadi M. – The estimation of per capita loadings of domestic wastewater in Tehran, Journal of Environmental Health Science & Engineering, **13** (25) (2015) 1-9.