Characterization of domestic wastewater discharge and its impact on material flows in urban Hue, Vietnam

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ACRONYMS AND ABBREVIATIONS

BOD	Biochemical oxygen demand
CIA	Central Intelligence Agency [US]
COD_{Cr}	Chemical oxygen demand determined by Dichromate Potassium
DES	Department of Environmental Science
DWF	Dry weather flow
GSGES	Graduate School of Global Environmental Studies
GSO	General Statistics Office
HH	Household
HUSC	Hue University of Sciences
HEPCO	Hue Urban Environment and Public Works State Co., Ltd
HUEWACO	Thua Thien Hue Construction and Water Supply State Co., Ltd
KU	Kyoto University
LBERI	Lake Biwa Environmental Research Institute
MFA	Material Flow Analysis
N	Nitrogen
OSS	On-site sanitation system
P	Phosphorus
PC	Personal computer
TSS	Total suspended solids
TN	Total nitrogen
TP	Total phosphorus
UNEP	United Nations Enviroment Program
VND	Vietnamese Dong
VSS	Volatile suspended solids

WHO	World Health Organization
WB	World Bank
WWTP	Wastewater treatment plant

ABSTRACT

Under the pressure of rapid urbanization and economic growth, the protection of water environment has become more difficult and urgent than ever. The weak management of material flows in urban areas has led to a great amount of pollutant flows come to the environment and caused the serious pollution. It has been considered that surface and ground water pollution is one of the biggest environmental concerns in urban areas in developing countries. Since domestic wastewater discharge potentially has impact on material flows, a well understanding of its characteristics and impact can help in identifying solutions for better management of material flows. However, wastewater discharge has been not well characterized in most developing countries. This research aims to study the characteristics of domestic wastewater discharge and its impacts on the material flows in urban areas in developing countries. The specified objectives of this research are:

1. To study the characteristics of domestic sewage discharge, focusing on quantity and quality fluctuations over time.
2. To understand the water flows in a combined sewer system by establishing water balance.
3. To quantify the impact of domestic sewage discharge on material flows in urban areas by a material flow model.

The research was conducted with a case study in an 11.2 ha sewer drainage area in urban Hue, Vietnam. Sewer surveys were conducted at the sewer outlet on dry days and rainy days in dry seasons and rainy seasons in year 2014, 2015, and 2016 to investigate the quantity, quality and the fluctuation of sewer discharge over time. A survey on hourly water consumption and a structure interview on wastewater management were also carried out to obtain additionally necessary information of the target drainage area. Then, pollution loads from sewer system were estimated and *L-Q* equations for main pollutants were obtained to understand the relationship between flow rates and pollution loads. Finally, a water balance and a material flow model were developed to quantify the impacts of sewer discharge on material flows in study area.

The research found that average discharge at the sewer outlet on dry days in dry season was 2.72±0.32 m^3/h (44.9±5.4 L/cap/day) in 2015 and 2.27±0.44 m^3/h (37.5±7.3 L/cap/day) in 2016, which was about half of that on dry days in rainy season (4.99±0.55 m^3/h (82.5±9.1 L/cap/day) in 2015, and 5.38±2.15 m^3/h (88.9±35.5 L/cap/day) in 2014). Average daily discharge on dry days was different among dry days. Hourly discharge flow rates on dry day fluctuated corresponding to the water consumption trends. Two peaks of discharge rates were observed on dry days from 6:00 - 16:00 and from 16:00 - 0:00, and the lowest rates were in the early morning (1:00 - 6:00). Meanwhile, discharge flow rates in rain events were affected by rainfall intensities. Stronger rainfall intensities corresponded to higher discharge flow rates. Domestic wastewater discharge in urban Hue was characterized by low concentrations of SS, nutrients, and organic matter with small proportion of particulate matter. In rain events, pollution concentrations increased at the beginning of rain and reach at peaks when rainfall intensities were around 7.5 mm/h, which were observed as the first flush phenomenon. After that pollutants concentration decreased while rainfall intensities and flow rates kept increasing, this was due to dilution caused by large flows. This made the concentration of pollutants during rainy time lower 3- 10 times than those on dry days. Unit pollution loads in drainage area on dry days were lower than those in other areas. Hourly pollution loads followed the hourly discharge flow rate. The development of *L-Q* equations showed that SS and VSS loads tended to increase the most greatly with the discharge flow rate, followed by COD_{Cr} and BOD_5, TP and TN. NH_4^+ was the parameter showed the lowest increase with the increase of flow rate. Dissolved matter mainly contributed to the total load on dry days while particulate matter has a great contribution to total load at the beginning time of rain.

Water balances of the combined sewer system were similar for all dry days in both dry season and rainy season. On dry days in dry season, discharge flow rate at the sewer outlet to the water body only accounted for 28.5% (in 2016) – 34.0% (in 2015) of total wastewater inputted the sewer system. It means a large amount of wastewater (66.0% -71.5%) might exfiltrated into the ground though sewer leakage. The large amount of exfiltrated water should be paid attention to since it might contaminate soil and groundwater. Meanwhile, on rainy days, water balance seemed show different patterns at different rainfall intensity days. There might be water exfiltration from the sewer

system on a light rainy day (14 mm/event) while there was water infiltration from the ground to the sewer system on a heavy rainy day (52.5 mm/event).

Phosphorus (P) and nitrogen (N) flow models were developed in the target drainage area on average dry days in dry season 2016, average dry days in rainy season 2015, and two rainy days with different rainfall intensities in rainy season 2015. P inputted the sewer system on dry days were mainly from household greywater (73.1 g P/(ha·day) – 52.0% of total P input to sewer system) and on-site sanitation system effluent (67.6 g P/(ha·day) – 48.0% of total P input to sewer system). Meanwhile, N came to sewer system was mainly from on-site sanitation effluent (506.5 g N/(ha·day) – 80.6% of total N input to sewer system). Compared to other components, sewer system was the main source of P and N loads to the water body, which contributed 91.0% - 99.2% of total P and 95.6% - 99.6% of total N inputted the water body. Besides, the amount of P and N discharged to the water body from the sewer system varied strongly at different weather conditions. On dry days in dry season, P and N amount discharged to the water body were 20.7 g P/(ha·day) and 273.5 g N/(ha·day), which were accounted for 14.7% of total P and 43.5% of total N inputted the sewer system. A similar amount of P and N discharged to the water body was observed on dry days in rainy season. There was a great amount of P and N stored inside the sewer pipes and/or came to the ground on dry days, which might cause by the low velocity of sewage flow on dry days and/or sewer leakage. On rainy days in rainy season, P and N amount discharged into the water body increased greatly under the impact of heavy rain, which were many times higher than those on dry days in dry season. It is demonstrated that there were some other sources such as accumulated sludge inside sewer pipes and/or water infiltration from the ground added more P and N into the total P and N budget of the sewer system on these days.

Keywords: combined sewer system, domestic wastewater, flow rate, greywater, Hue Citadel, MFA, nutrient, pollution load, rainfall, sewer discharge, Vietnam, water balance, water body.

Chapter 1 Introduction

1.1 Research background

Nowadays, developing countries are under high pressures of economic development and rapid urbanization. Urban areas in these countries play greater roles in consuming and producing water and nutrient products to satisfy increasing urban population demands. However, the improper water and nutrients-contained wastewater management affected to material flows, leading to serious environmental concerns in those areas.

1.1.1 Domestic wastewater management in urban areas in developing countries

Presently, 54% of global population is living in urban areas (UN-ESA, 2014). Urban areas are both consumers of great amount of water and producers of equivalent amounts of wastewater. It was estimated that 330 km^3 of domestic wastewater is produced every year globally (Hernández-Sancho *et al.*, 2015). The domestic wastewater amount will keep increasing in the near future since the percentage of urban population is predicted to be increased up to 66% by 2050 (Hernández-Sancho *et al.*, 2015). This is a global problem since many cities in the world are still lacking adequate wastewater treatment facilities.

This problem is more serious in developing countries where nearly 90% of the increase of urban population is predicted to be concentrated by 2050 (Hernández-Sancho et al., 2015) while wastewater management is still very weak (**Table 1-1**). In most urban areas in developing countries, the wastewater infrastructure is non-existent, inadequate or outdated (Corcoran *et al.*, 2010) which is unable to keep pace with rising urban population. From 80-90% of wastewater generated in developing countries is discharged directly into surface water bodies without comprehensive treatments (Corcoran *et al.*, 2010). In Southeast Asia, 13 million tons of feces, 122 million m^3 of urine and 11 billion m^3 of grey water are released to inland water sources each year (World Bank, 2008).

Table 1-1 The state of sanitation in some countries in Asia (AECOM International Development, Inc. and Sandec – Eawag, 2010)

	Indonesia	Malaysia	Philippines	Thailand	India	Sri Lanka	Vietnam
Population (in milliions)	222	28	88	63	1150	19	86
Urban population (in millions)	93	18	54	21	350	3	23
% Sewerage connections	2.3% (urban)	73% (national)	7% (urban)	NA	40% (urban)	4% (urban)	NA
% Sewage treated	<14%	100%	<10%	14%	9%	NA	4%
% Septic tank	62% (urban)	27% (national)	40% (national)	All but highly urbanized areas	29 (urban)	89% (nation)	77% (urban)
% Septage treated	4% (national)	100% (national)	5% (Metro Manila)	30% (national)	0% (national)	<1% (Nuwara Eliya)	<4% (national)
% Organic water pollution due to domestic wastewater	NA	NA	50%	54%	80%	NA	55% (Hanoi)
% Surface water polluted	75%	45% (Monitored rivers)	58% (Groundwater)	52%	75%	NA	NA

Note: NA: not available
<: less than

1.1.2 Water environment concerns under improper wastewater management in urban areas in developing countries

Under economic growth and rapid urbanization, improper water and nutrients-contained wastewater management affected to material flows, leading to the diffuse source contamination of surface water and groundwater.

Due to the lack of wastewater treatment facilities, the great amount of untreated nutrients-contained wastewater in urban areas has led to the global rising of water pollution (**Table 1-1**) and the most prevalent problem of surface water quality is eutrophication - a result of high nutrient loads to water bodies (Corcoran *et al.*, 2010). In China, surface water is suffering from various degrees of pollution due to ineffective management of discharged domestic wastewater. Up to 80% of urban rivers are being polluted with high concentrations of nitrogen, phosphorous, organic compounds, and heavy metals (Qu and Fan, 2010). Most of the urban lakes are facing serious eutrophication, algal blooming, water quality decreasing and lake's ecosystem declining (Jin *et al.*, 2005). In sub-Saharan Africa, Lake Victoria, Lake Albert, and many inland delta lakes and fresh water resources were reported to be in eutrophication condition due to the discharge of untreated sewage from urban areas (Nyenje *et al.*, 2010). Surface and groundwater contamination by organic matters, *Escherichia coli*, nutrients, heavy metals, *etc.* were also reported in many other developing countries or regions such as India (Dixit *et al.*, 2005; Trivedi, 2014), Brazil (Couceiro *et al.*, 2006), South Africa (van Ginkel, 2011), West and Central Africa (Pare and Bonzi-Coulibaly, 2013), *etc.* Vietnam is also suffering the same situation. According to the report of the Ministry of Natural Resources and Environment, most lakes and rivers in inner cities were polluted (MONRE, 2010). In Hanoi, BOD_5 value of To Lich River is 17-25 times higher than Vietnamese standard for domestic water supply purpose (4 mg/L). Hop *et al.* (2012) also reported that almost all of the lakes and rivers in Hue Citadel, Hue city were in hyper-eutrophic states.

In addition, due to the poor maintenance of wastewater infrastructures, potential pollutant leaching from domestic wastewater may result in contamination in groundwater. Groundwater pollution has been reported in many urban areas in India (Rai and Saha, 2015; Asadi *et al.*, 2015), Cameroon (Kringel *et al.*, 2016), *etc.* Domestic wastewater was identified as one of the main sources in causing groundwater nitrate pollution in urbanized areas in China (Zhang *et al.*, 2015). A survey of groundwater nitrate-N concentration in China showed that 45% of 600 groundwater samples exceeded the WHO standard for nitrate in drinking water (50 mg NO_3^-/L) (Zhang, 2004). According to Cam (2008), a significant number (18%) of samples in Vinh Phuc province, Vietnam had nitrate concentrations in excess of the WHO standard for drinking water.

Polluted water sources in turn affect human health. Waterborne disease is considered as world's leading killer. It was reported that 80% of all illnesses and deaths in the developing world was due to water related disease (UN, 2003). In adequate sanitation, poor hygiene and unsafe water is responsible for around 88 per cent of all diarrheal incidents (Corcoran *et al.*, 2010). Childhood malnutrition, which is the cause of 35% of all global child mortality, is related to repeated diarrhea or intestinal worm infections (WHO/UNICEF, 2008).

1.2 The rationality of the study

To deal with these issues, the impacts of domestic wastewater discharge on material flows in urban areas of developing countries required to be quantitatively understood to design a sound water and nutrient management. To clarify those impacts, it is crucial to assess the current status of water balance and update wastewater discharge characteristics, which are still very limited and/or outdated in developing countries. Reality has shown that data in all aspects of wastewater quantity, quality, and fluctuation over time and climate conditions are lack or very old in developing countries (a great number of data was before 2008) (UN, 2015; Sato *et al.*, 2013). Collecting adequate information on domestic wastewater discharge in urban areas should be the initial and essential step in the long term planning of clarifying their impact to material flows and then improving urban water environment in developing countries.

1.3 Purposes

The overall objective of the research is to study the characteristics of domestic wastewater discharge and its impact on material flows in urban areas in developing countries based on a case study in urban Hue city, Vietnam.

The specific objectives include:

1. To study the characteristics of domestic sewage discharge, focusing on quantity and quality fluctuations over time.
2. To understand the water flows in a combined sewer system by establishing a water balance.
3. To quantify the impact of domestic sewage discharge on material flows in urban areas by a material flow model.

This dissertation consists of seven chapters. The outline is given as follows:

Introduction (Chapter 1)

- Introduction of this dissertation

Literature reviews (Chapter 2)

- Overview of domestic wastewater characterization: studies on domestic wastewater characterization together with their remarkable findings were introduced.
- Overview of material flow analysis (MFA): basic knowledge on MFA (definition, terminology and MFA procedure) and current state of using MFA in environmental management in many urban areas were introduced.

Overview of waste and wastewater management in Hue, Vietnam (Chapter 3)

- Overviews of waste and wastewater management in urban areas of Vietnam: current state of drainage network and domestic wastewater management in Vietnam were summarized.
- Overviews of waste and wastewater management in Hue city: information on water supply and sanitation facilities, domestic solid waste management, drainage network and domestic wastewater management in Hue city were summarized.

Domestic sewer discharge characteristics (Chapter 4 and 5)

- The study of sewer discharge characteristics: quantity and quality of a combined sewer discharge were characterized by a survey at the sewer outlet of a residential drainage area in urban Hue city. The variations of discharge flow rate and quality over time were investigated through a 24-hour survey on dry days and rainy days in dry season and rainy season. From the obtained flow rate and concentration of sewage, pollution loads from the target drainage area were estimated. The relationship between pollution loads and flow rates were also examined.
- The study of water balance in a combined sewer system: from the data obtained from sewer surveys and secondary data collection, a water balance for the combined sewer system was constructed. Then, the ratio of water infiltration/exfiltration was estimated.

Impacts of sewer discharge on material flows in urban areas (Chapter 6)

- The study of material flows in the target drainage area: MFA was applied to develop nutrients (N and P) flows models in the target drainage area. Information of sewer discharge was used for the calculation of material flows related to sewer system component to quantify the impact of sewer discharge on nutrient flows in urban Hue.

Conclusions and recommendations (Chapter 7)

- Conclusions of this dissertation and recommendations for further studies

Structure of the dissertation is shown in **Figure 1-1**.

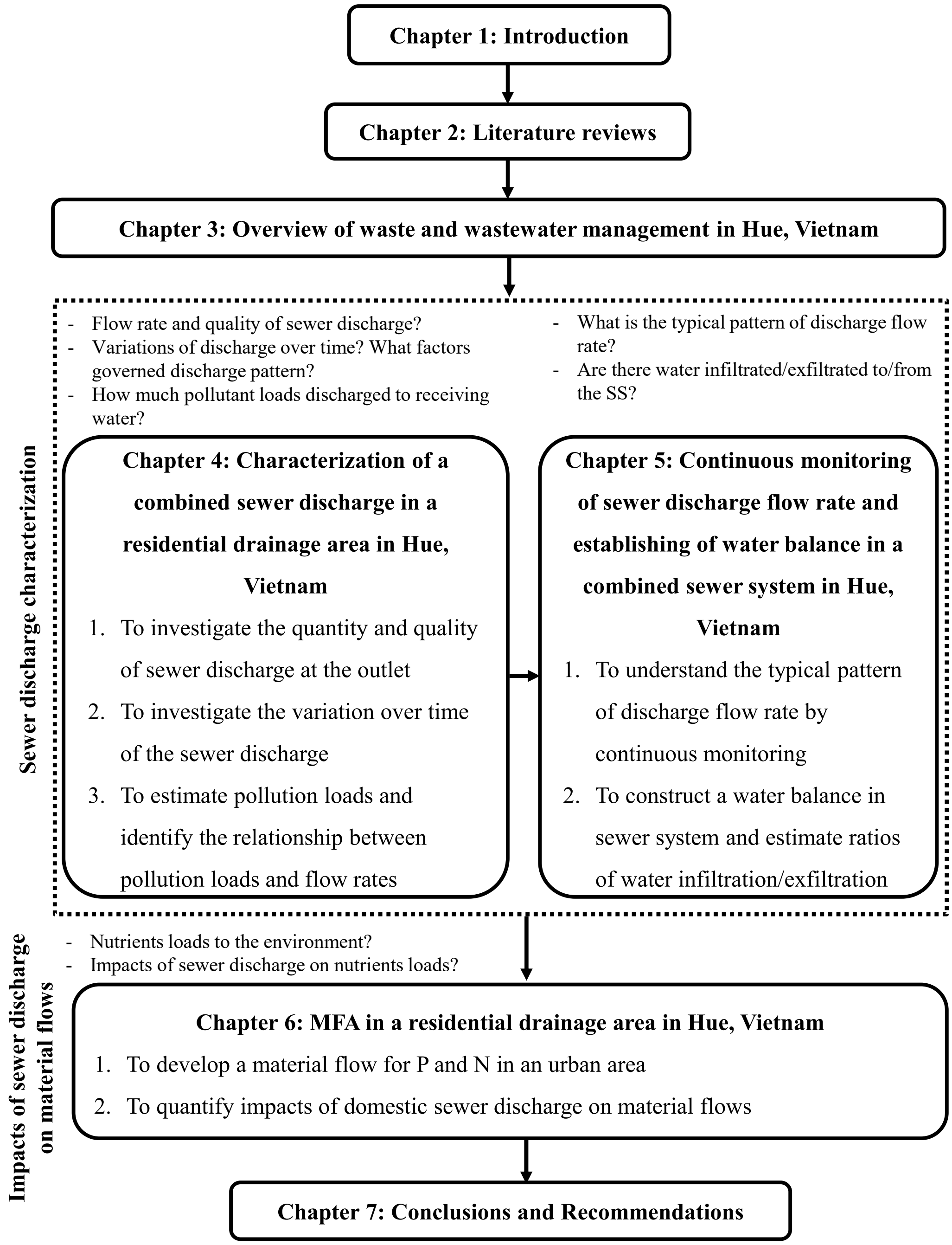

Figure 1-1 Research framework

1.4 Internships and surveys in Vietnam

The Graduate School of Global Environmental Studies (GSGES), Kyoto University offers students an internship program in the Environmental Management course, which requires at least five months in doctoral courses in the graduate school. The author completed a five-month-internship and other three months for survey and data collection related to the research. Moreover, the author spent around one month at Lake Biwa Environmental Research Institute (LBERI) to learn methods of water quality analysis. Schedules and contents of all internships are listed in **Table 1-2**.

Table 1-2 Schedule of internships and surveys

Schedule	**Content**	**Host institute**
November 11th 2013 – January 31st 2014	Training on water quality and aquatic organisms sampling and analysis	LBERI
February 15th – March 30th 2014	Survey on water use, waste and wastewater management in Hue Citadel, Hue city, Vietnam	DES, HUSC
October 2nd – November 27th 2014 and November 3rd – December 25th 2015	Survey on combined sewer discharge in rainy season in a residential drainage area in Hue city, Vietnam	DES, HUSC
July 2nd – August 27th 2015	Survey on combined sewer discharge in dry season in a residential drainage area in Hue city, Vietnam	DES, HUSC
January 17th – February 10th 2016	Continuous monitoring of sewer discharge flow rate in a residential drainage area in Hue city, Vietnam	DES, HUSC

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Chapter 2 Literature reviews

2.1 Domestic wastewater discharge characterization

In developed countries, characteristics of wastewater in general and of domestic wastewater in particular were paid attention to and investigated rather soon. Up to now, basic information on domestic wastewater generation and discharge were well known and written in many textbook (Tchobanoglous *et al.*, 2004; Henze *et al.*, 1997; Von Sperling *et al.*, 2007; Davis and Cornwell, 2013; *etc.*). Typical hourly variations of wastewater flow rate during a day were described in “Wastewater engineering - Treatment and reused” (Tchobanoglous *et al.*, 2004). Typical wastewater constituent concentrations and loads for various countries were supplied. Untreated domestic wastewater concentrations were also classified into three levels: low, medium and high strength. Volumes and composition of wastewater were presented by Henze *et al.* (1997), which emphasized the variations over time of wastewater flow and pollution loads and classified contents of organic matter, nutrients, metals, and other different parameters in domestic wastewater into four categories: concentrated, moderate, diluted, and very diluted.

Characteristics of domestic wastewater were investigated at-sources (Daniel *et al.*, 2014; Umuhoza Mbateye *et al.*, 2010; Butler *et al.*, 1995; Almeida *et al.*, 1999, *etc.*) and also at the discharge point from sewer systems (Karagozoglu *et al.*, 2003; Schaarup-Jensen *et al.*, 1998) or in the influent of wastewater treatment plants (Pinto *et al.*, 2005; Williams *et al.*, 2011). The sub-daily variations of flow and pollutants concentration throughout the day in England and Malta were described by Butler *et al.* (1995). Per capita domestic wastewater discharge varied during 24 hours and had three peaks, one morning peak and two evening peaks. Lowest discharge was found at late night and midday. The studies also revealed that domestic wastewater quality undergoes significant variations during the day. These variations were explained by checking the contribution of each household appliance. Diurnal pattern for concentration and load in wastewater for COD, PO_4, TSS, NH_3, and NO_3 at the households in residential urban and suburban areas of south-east England was investigated by Almeida *et al.* (1999). The total load from households showed a pattern with a high morning peak (6:00-9:00) and a lower evening peak (17:00-21:00). The origin of wastewater volumes and pollutant loads was also identified for individual appliances and modes of usage. WC and kitchen sink were found to be the appliances that most contribute towards wastewater production in terms of volumes and for the majority of determinants.

Besides the fluctuation of wastewater characteristic over time, the differences over space were also examined. Wastewater quality and pollutant loads in combined sewers during dry weather periods were investigated in six catchments on the right bank of the Seine River in Paris by Gasperi *et al.* (2008). Similar pollutant concentrations and loads in six catchment implied that similar production and in-sewer transfer processes occurred for catchments which have the similar land use and sewer characteristics. Discharge characteristics of each individual pollutant in domestic wastewater were also studies in detail.

In wet weather condition, under the impact of rain, sewer discharge flow and quality changed very much compared to dry weather flow. Flow and quality as well as pollution loads from sewerage system in wet weather condition were monitored in many developed countries (Kafi *et al.*, 2008; Sandoval *et al.*, 2013; *etc.*). A study in Boran-sur-Oise, France (Bertrand-Krajewski *et al.*, 1995) showed that compared to dry weather loads, the influent loads during a storm event were respectively 10, 1.2, and about 3 times greater for total suspended solids (TSS), ammonia and BOD_5. However, the concentration of each parameter had its own evolution, TSS concentration increased while ammonia concentration decreased, and COD or BOD_5 concentrations were equivalent to dry weather periods' concentrations. The relationships between rainfall, flow rate, and pollutants concentrations in wet weather condition in the influent at 24 WWTPs at Georgia, U.S. were evaluated by Mines *et al.* (2007). The correlations were observed from moderate to strong, and dilution effect was also observed to cause to decrease of pollutants concentration.

Combined sewer overflow (CSO) during wet weather condition has been of great interest in most of sewerage system studies since CSO can impact receiving water's quality (Li *et al.*, 2010; Diaz-Fierros *et al.*, 2002; Su´arez and Puertas, 2005, Gasperi *et al.*, 2012; *etc.*). The contribution of various sources to the total flow was investigated in Greater Milwaukee, U.S (Soonthornnonda and Christensen, 2008). Sanitary sewage accounted for from 27% - 56% of the total overflow, and most of the remaining water source was from stormwater with possible minor contribution (≤ 8%) from groundwater. Most total suspended solids and metals were from stormwater, while BOD_5, NH_3, and total phosphorus were mainly from sanitary sewage (≥ 28%), especially NH_3 (≥ 58%). A study in Paris, France showed the similar pattern in which the erosion of in-sewer pollutant stocks was found to be the main source of particles and of organic matter in wet weather flows, whereas heavy metal loads mainly originated from roof runoff (Gromaire *et al.*, 2001). Besides investigating the pollution sources in wet weather condition, the quality of these sources was also examined.

Infiltration and exfiltration are two of phenomena related to sewerage system which were concerned since they can result in contaminating of ground water and cause adverse impacts to the operation of sewerage system. Many studies tried to estimate the ratio of infiltration/exfiltration and to understand the mechanism of these phenomena. Various methods were used in an attempt to quantify sewer exfiltration rates, such as direct measurement of flow in isolated sewer segments in The United States (Amick and Burgess, 2000), theoretical estimates using Darcy's Law and related hydraulic theory European's studies (Amick and Burgess, 2000), estimate based on water/sewage balance calculation in United Kingdom (Rueedi *et al.*, 2009), *etc*. The ratio of exfiltration varied strongly among areas (**Table 2-1**) and was affected by many factors such as age of the system, local ground condition, *etc.* (Bishop *et al*., 1998).

Table 2-1 Exfiltration rates in various areas

Area	Method	Exfiltration rate	Reference
California, USA	Direct measurements	34% - 56% of DWF	(Amick and Burgess, 2000)
Washington, USA	Direct measurements	16.6% - 49.1% of DWF	(Amick and Burgess, 2000)
Kentucky, USA	Direct measurements	11.9% - 34.5% of DWF	(Amick and Burgess, 2000)
Doncaster, UK	Water mass balance	5% - 10% of DWF	(Rueedi *et al.*, 2009)

Linz, Austria	Ground water flow modelling	1% of DWF	(Fenz *et al.*, 2005)
Ru¨mlang, Switzerland	Balance of artificial tracer load	9.9% of DWF	(Rieckermann *et al.*, 2005)

Note: DWF: dry weather flow

In developing countries, study on wastewater management has been interested in recent years when water environment is getting worse and wastewater treatment facilities has been focus on development. Physico-chemical characteristics of domestic wastewater were investigated in India (Bai *et al.*, 2010; Sonune *et al.*, 2015; Binki *et al.*, 2015), Nigeria (Uwidia and Ukulu, 2013), Thailand (Tsuzuki *et al.*, 2010), Vietnam (Dao *et al.*, 2010; Nga *et al.*, 2014), *etc.*, which supplied a glimpse on wastewater characteristics in these areas. Pollution load from domestic wastewater was also one of concern and was estimated in Vietnam (Anh *et al.*, 2014), Iran (Mesdaghinia *et al.*, 2015). Besides, short-term and long-term variations of wastewater flow rate and concentration – one of the important characteristics of wastewater were also investigated by some studies in Pakistan (Haider and Ali, 2012), Kuwait (Almedeij and Aljarallah, 2011), Romania (Popa *et al.*, 2012). Diurnal variations of flow and pollutants concentrations were monitored at the Main Outfall disposal station of the city of Lahore, Pakistan (Haider and Ali, 2012). Temperature, pH and TDS in the wastewater did not show significantly change among hour during a day. Meanwhile, flow rate, TSS, VSS, and BOD5 are higher during the day period than those during the night time. Almost all the wastewater parameters including flow were lowest at 6:00 AM – the time that all activities have not been initiated in the city. The seasonal variations of wastewater influent at treatment plants in Kuwait were investigated (Almedeij and Aljarallah, 2011). The long-term trend from 1999 to 2009 of wastewater influents was related to the population growth, while short-term seasonality trend was reflecting the changing mode of people for watering or travel activities during the year and the illegal connection of storm sewers into the sanitary networks in many residential houses. The influent is low in February, June, July, August, and September, for the months considered holidays in Kuwait, and high in October, November, December, and January because of rainfall events.

These studies have made a contribution in supplying more information on domestic wastewater in developing countries where this kind of information is lacking. However, it is obvious that wastewater information and data in developing countries is still rather limited in comparing to developed countries and has not met the requirement of wastewater management in this area. More studies on this field should be continued conducting in developing countries to obtain a comprehensive knowledge of domestic wastewater characteristics, which can play a foundation for better management of urban wastewater in this area.

2.2 Application of material flow analysis (MFA) in urban environment management

2.2.1 Introduction of MFA

Definition

The basic principle of any MFA - the conservation of matter, or input equals output - was first postulated by Greek philosophers more than 2000 years ago. The first studies in the fields of resource conservation and environmental management appeared in the 1970s. The two original areas of application were (1) the metabolism of cities and (2) the analysis of pollutant pathways in regions such as watersheds or urban areas. In the following decades, MFA became a widespread tool in many fields, including process control, waste and wastewater treatment, agricultural nutrient management, water-quality management, resource conservation and recovery, product design, life cycle assessment (LCA), and others (Brunner & Rechberger, 2004).

As defined by (Brunner & Rechberger, 2004): "Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process. It is this distinct characteristic of MFA that makes the method attractive as a decision-support tool in resource management, waste management, and environmental management".

The results of MFA will be used as a basis for managing resources, the environment, and wastes, in particular for (Brunner & Rechberger, 2004):

- Early recognition of potentially harmful or beneficial accumulations and depletions of stocks, as well as for timely prediction of future environmental loadings

- The setting of priorities regarding measures for environmental protection, resource conservation, and waste management (what is most important; what comes first?)

- The design of goods, processes, and systems that promote environmental protection, resource conservation, and waste management (green design, eco-design, design for recycling, design for disposal, etc.)

Terminology of MFA (Brunner & Rechberger, 2004)

Substances

MFA relies on the term substance as defined by chemical science. A substance is any (chemical) element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogeneous.

Chemical element such as carbon (C), nitrogen (N), phosphorus (P) or chemical compounds such as carbon dioxide (CO2), ammonium (NH3) are substances.

Good

Goods are defined as economic entities of matter with a positive or negative economic value. Goods are made up of one or several substances.

Examples for goods are drinking water, garbage, sewage sludge, *etc.*

Material

In MFA, material is used for both substances and goods.

Nitrogen as well as garbage can be addressed as a material.

Process

A process is defined as the transformation, transport, or storage of materials.

Examples of process are: dispose garbage to landfill site, discharge wastewater into water bodies, natural sedimentation, *etc*.

Flow and flux

The actual exchange of materials determined for a system is designated as a flow (mass per time). Only specific flows that are related to a cross section are designated as fluxes (mass per time and cross section). The advantage of using fluxes is that they can be easily compared among different processes and systems, since fluxes are specific values.

Component

Component is defined as a platform to convey the flows of goods or substances. For example, household is a component to convey nutrients from market to landfill or water body.

System and system boundary

The system is the actual object of an MFA investigation. A system is defined by a group of elements, the interaction between these elements, and the boundaries between these and other elements in space and time. In MFA, the physical components are processes, and the connections/relations are given by the flows that link the processes. A single process or a combination of several processes can represent a system.

The system boundaries are defined in time and space (temporal and spatial system boundary). The temporal boundary depends on the kind of system inspected and the given problem. It is the time span over which the system is investigated and balanced. Theoretically it can range from 1 sec for a combustion process to 1000 years for landfills.

The spatial system boundary can consist of geographical borders (region) or virtual limits (e.g., private households, including processes serving the private household such as transportation, waste collection, and sewer system).

MFA procedure

The procedure of MFA is illustrated in **Figure 2-1**. An MFA begins with the definition of problem and goals. Then relevant substances and appropriate system boundaries, processes, and goods are identified. Next, mass flows of goods and substance concentrations in these flows are assessed. The mass–balance principle applies to systems as well as processes. According to the mass-balance principle, the mass of all inputs into a process equals the mass of all outputs of this process plus a storage term that considers accumulation or depletion of materials in the process. If inputs and outputs do not balance, one or several flows are either missing or they have been determined erroneously, and they have to be rechecked. A true material balance of a process or system is only achieved if all input and output flows are known, and if either $m_{storage} = 0$ or $m_{storage}$ can be measured. In general, it is best to start with rough estimations and provisional data, and then to constantly refine and improve the system and data until the required certainty of data quality has been achieved. The results are presented in an appropriate way to visualize conclusions and to facilitate implementation of goal-oriented decisions (Brunner & Rechberger, 2004).

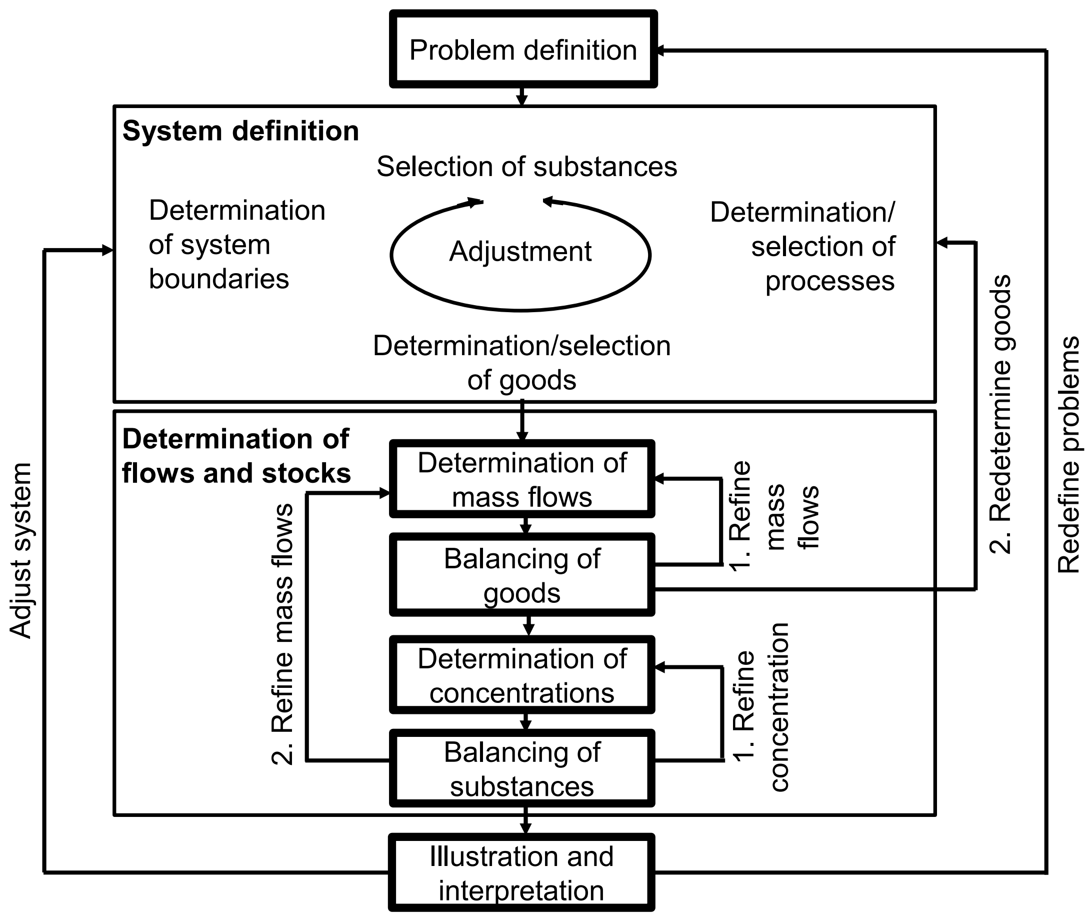

Figure 2-1 MFA procedure (Brunner & Rechberger, 2004)

2.2.2 Application of MFA in urban environment management

As a strong systematic tool for assessing environmental impacts, MFA were applied in many studies in developed and developing countries. The researchers applied MFA to determine the main input routes to the targeted system, the stocks and flows within the system, the emission processes, as well as the chemical, physical, biological transformations, and resulting in the environment.

In Sweden, Nilsson (1995) illuminated the ecological interplay between the city and countryside by studying the flow of phosphorus from the ecosystem to the community and back to the ecosystem in the Swedish municipality of Gayve. In the United States, Brock *et al*. (1998) applied MFA to construct a phosphorus mass balance for the Washington-Sammamish watershed, especially the impacts of phosphorus loading to the watershed. In Australia, by the method of MFA, Tangsubkul *et al*. (2005) developed a phosphorus balance and explored its connection with wastewater management at a city level.

In developing countries, they recently are under high pressure of economic development and rapid urbanization, leading to urgent environmental issues in those areas. Greater waste and wastewater generation and their improper management, over exploitation of natural resources, and urban water environmental pollution are growing concerns. To deal with these issues, it is required to understand the nutrient cycles and the manners of waste management for approaching a better urban environmental management. Several studies have been conducted in developing countries using MFA. In China, Ma *et al.* (2008) analyzed the nitrogen flow in Huizhou City in the East River watershed in south China to address the serious eutrophication due to uncontrolled discharges of nitrogen and phosphorus in many Chinese rivers. Similarly, Li *et al.* (2010) employed the method of MFA to examine phosphorus flow and its connection to water pollution in the city of Hefei. In Thailand, Buathong *et al.* (2013) quantitatively analyzed domestic wastewater and nitrogen flows by MFA and proposed implemented solutions by scenario simulation based on area zoning analysis, which were aimed for better sanitation management.

Similar to other developing countries, Vietnam are now facing with rapid economic growth and consequently, serious environmental management issues. In urban areas, greater and improper domestic waste and wastewater discharge to water bodies resulted in serious pollution and eutrophication in rivers, lakes, and ponds in those areas. Nhue-Day, Cau, and Dong Nai river basins are three largest river basins in Vietnam and have been reported to be polluted at an alarming level (Environmental Report of Vietnam, 2006). Since the serious consequence of improper management of wastes and nutrients to the urban environment, several researches have addressed the wastes and nutrient management recently. Montangero *et al.* (2007), Harada *et al.* (2010), Nga *et al.* (2011), and Giang *et al.* (2015) applied MFA to develop nutrient flows and to estimate nutrient loads to the environment in Vietnam for designing a sound water and nutrient management. EAWAG/SANDEC and its partners in Vietnam have developed a tool which links urban organic waste/wastewater management and urban agriculture to estimate and visualize water and nutrient flows in a region (Montangero, 2010). The tool was based on MFA and was designed to support local actors in analyzing the impacts of nutrient management in the environment and then proposing a better environmental management.

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Chapter 3 Overview of waste and wastewater management in Hue, Vietnam

3.1 Waste and wastewater management in urban areas of Vietnam

3.1.1 General description of Vietnam

Vietnam, officially the Socialist Republic of Vietnam, is the easternmost country on the Indochina Peninsula in Southeast Asia. The country is bordered by China to the North, Laos and Cambodia to the West, the Gulf of Thailand in the Southwest, and the South China Sea to the East and South (**Figure 3-1**). The country is divided into 63 provinces including the capital Hanoi. The total area of the country is 330,967 km^2 (**Table 3-1**). Its terrain is characterized as low and flat delta in the south and north, highlands in the central, and hilly and mountainous in the far north and northwest (CIA, 2015). Because of its geography, the climate in Vietnam varies greatly from north to south with three distinct climatic zones. Tropical monsoons occur from October to April in the center and from May to September in the north and south. It is almost totally dry throughout the rest of the year.

Figure 3-1 Map of Vietnam (CIA, 2015)

The total population in 2014 was around 90.7 million (GSO, 2014), which is 13th most populous country in the world. Vietnam is ranked in lower middle income with a GNI in 2014 of 1,890 US$ per capita per year. Percentage contribution of agriculture, industry, and services to total GDP in 2014 was 18.1%, 38.5% and 43.4%, respectively (CIA, 2014).

Table 3-1 General information of Vietnam

Item	Unit	Data	Ref
Area	km^2	330,967	GSO, 2014
Total population	1000 people	90,728.9	GSO, 2014
Density	inhabitant/km^2	274	GSO, 2014
Urban population	1000 people	30.035,4	GSO, 2014
Rural population	1000 people	60.693,5	GSO, 2014
GDP	Billion current USD	186.2	WB, 2014
GNI, Atlas method	Current USD/capita/year	1,890	WB, 2014

Up to September 2013, Vietnam had 765 urban areas classified into six categories. At present, 33.1% of total population was living in urban areas (GSO, 2014) and this number will keep increasing due to the rapid urbanization. The number of urban areas is expected to rise to 1,000 by 2025 with a total estimated urban population of 52 million (Tien, 2013). The process of rapid urbanization and population growth has created huge pressures on infrastructure systems which were backward - built decades ago, especially urban drainage and sewerage systems. Results of water quality monitoring of major canals, lakes and rivers in Vietnam showed that concentrations of organic pollutants are 1.5 to 3 times, or even 10-20 times higher than the permitted standard in some areas (VEA, 2010).

3.1.2 Sewerage system and domestic waste and wastewater management in urban areas of Vietnam

Household waste and wastewater management

Wastewater from households is mainly pre-treated in household's septic tank together with toilet effluent before being discharging into sewer systems, and then into water bodies (rivers, lakes, canals, *etc.*) without any further treatment, except in some big cities such as Hanoi and Ho Chi Minh City. According to World Bank (2010), the rate of population having access to sanitation services in 2008 is 91%, of which, septic tanks are the most common sanitation type in urban areas (accounting for 80% of the total households). The remaining households are either equipped with other type of onsite sanitation such as double vault latrines, pit latrines, *etc.* or directly discharge their wastewater into combined sewers without any treatment. Many households have latrine with septic tank but it is not connected to the sewerage system due to the lack of sewerage network in small lanes. As a result, wastewater flows into open small channels or to surrounding areas or infiltrates into soil. Some households have flush latrine, flushing directly wastewater into the common sewerage system, bypassing septic tanks or other on-site treatment works.

Similarly to the wastewater situation, septage (liquid and solid material pumped from a septic tank, cesspool or other primary treatment source) has not been treated properly before being discharged into environment. Many households have not conducted sludge removal from their septic tank for ten years. Wastewater; therefore, is discharged into a common sewerage sewer together with sludge from storage tanks, leading to a situation in which it is easy to get sediments in the sewer and there is a serious odor, especially in the dry seasons. In large provinces or cities, septage is often collected by the province or city-owned companies or private companies based on requests from households. In theory, this sludge should be transported to landfills or septage treatment facilities for final disposal. However, in reality, activities of sucking, transporting and disposing sludge in septic tanks from households have not been controlled and septage is often illegally dumped into vacant land, canals or ponds or even discharged directly into the rivers and ponds near sludge emptying points.

Drainage network

In Vietnam, most of the urban areas in category IV or higher have combined sewerage and drainage systems, which collect both rainwater and wastewater via pipeline collection networks or drainage canals. According to the water sector review report (ADB, 2009), the average drainage coverage in Vietnam is about 40–50%, which is much lower than water supply service of over 70%. The coverage rate ranges from 70% in large urban areas to only 10–20% in category IV.

Drainage systems in many urban areas in Vietnam started to be established in the period of French colony (when Vietnam was occupied by French colonialists). Many of them have deteriorated and do not function properly due to poor maintenance. In many urban areas, drainage systems just considerably developed in the past two decades, when the country moved to free economy.

Some newly developed urban areas introduce separate sewer and drainage systems. Several urban drainage projects were implemented, applying separate drainage option, typically Buon Ma Thuot city drainage project (funded by Danish government, put into operation in the first Phase from 2008), water supply and sanitation project for small towns in Vietnam (funded by Finnish government, starting to put into use).

Sewerage system is primarily serving as storm-water drainage, and "taking away" domestic wastewater to prevent flooding in the streets. Mainly for serving drainage of wastewater from central areas, drainage of surface water, preventing flood along with street routes. Gradually, when many construction works raised, connecting wastewater discharge outlets to the drainage system, the drainage systems became a common drainage systems with a situation of inconsistent construction and operation and not being able to meet the demand of drainage. In many places, routes of sewer have uncontrolled elevation, causing sediments and flood, leading to difficulties in the management of operation, maintenance and renovation. In the new urban areas, drainage systems are separate systems; however, because most of wastewater is not treated, wastewater and surface water from these urban areas flow together in sewer routes along with roads in the suburb or the main drainage channels of the city.

Approximately 92% of urban wastewater collection is done via the combined system; a separate system is used for the remaining 8%. As most urban wastewater is untreated, thus both storm-water and domestic wastewater are finally discharged together into nearby water environments such as rivers, lakes and canals.

These sewerage systems are normally managed by province or city-owned companies (sometimes also referred to as "state-owned companies"). According to the Assessment Report on Water Sector in Vietnam (ADB, 2009), there are 76 companies currently providing drainage and wastewater treatment services, in which there are 49 companies of the central cities or provincial cities, 23 categories IV urban areas at provincial level and 4 townships under city or provincial management. Out of those companies, only 4 companies belonging to Hanoi, HCM, Hai Phong Cities and Ba Ria - Vung Tau are specialized in providing services of drainage and wastewater treatment. The rest companies provide both services of drainage and wastewater treatment and other services such as solid waste collection, street management, green parks and urban lighting as well as cemeteries etc. The current management model of drainage services in big cities are mainly operated with a mechanism of ordering in which drainage enterprises are assigned by local governments to manage asset of urban drainage systems with the ownerships from provincial and city governments (channels, sewers, vehicles and facilities etc.). Operation and maintenance budget for drainage and wastewater treatment systems generally is from city or provincial budgets. Decree No 88/2007/ND-CP stipulated the necessity of collecting drainage fee from households to cover operation and maintenance cost of the drainage systems. However, drainage fee at present is commonly regulated as 10% additional of drinking water bill under supervision of the City People Committees. In general, this drainage fee only meets 10-20% of operation and maintenance cost for wastewater collection system, not covering sufficiently cost for operation and maintenance for wastewater treatment station (if any) and annual depreciation cost.

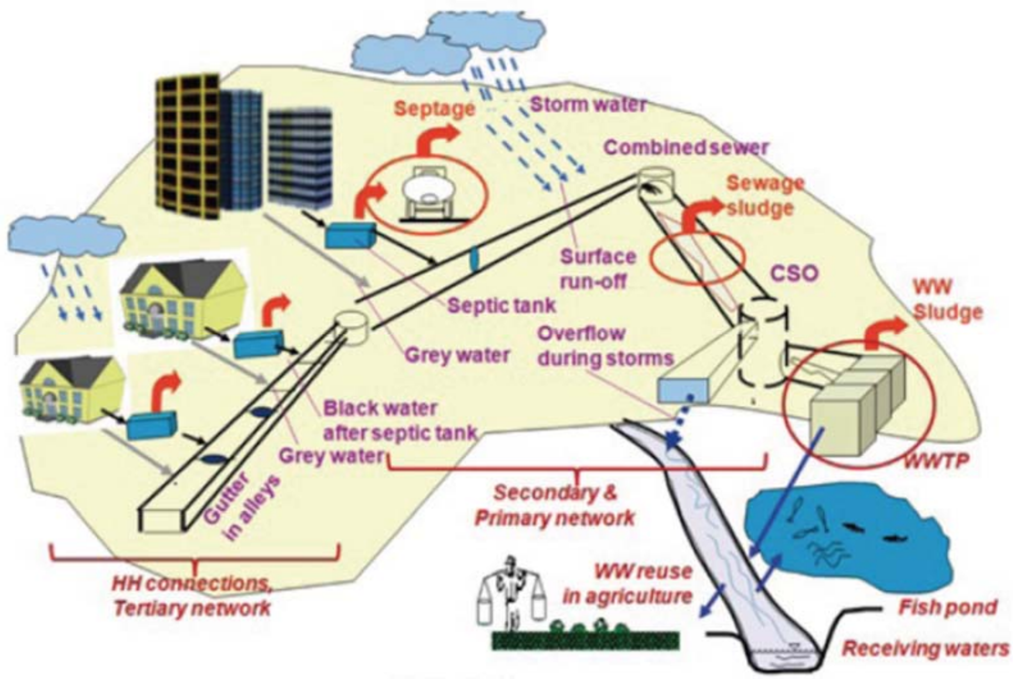

Figure 3-2 Typical combined sewer and drainage system found in cities of Vietnam (Hoa & Viet Anh, 2013)

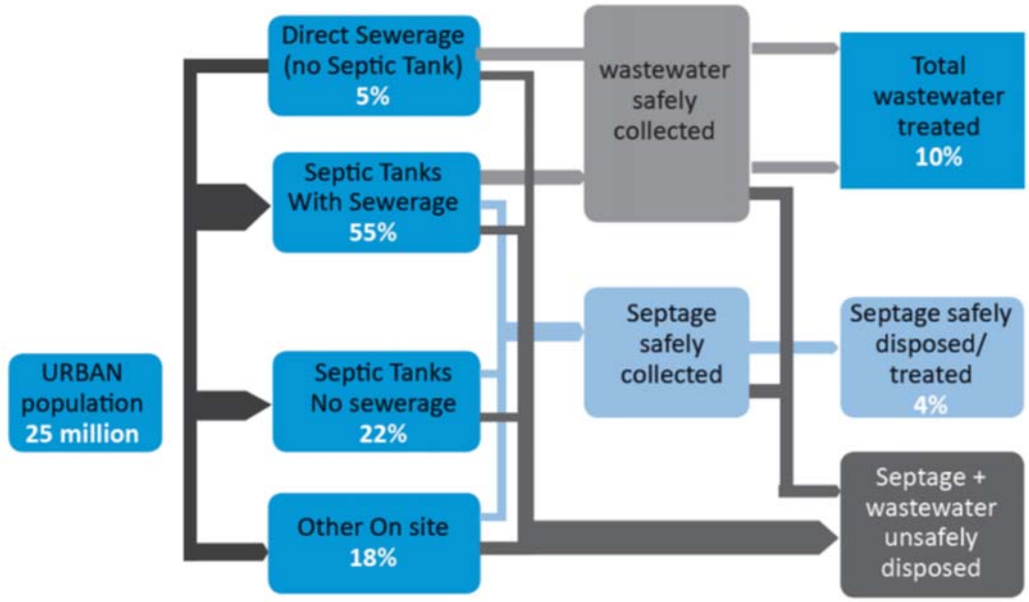

Figure 3-3 Status of urban wastewater management in Vietnam (World Bank, 2013)

Wastewater treatment plants

Most of the domestic wastewater in urban areas is not centrally treated in WWTPs except few big cities. According to the Ministry of Construction, before Nov. 2013 only eight urban areas in Vietnam had centralized wastewater treatment plants, mainly in big cities including Hanoi, Ho Chi Minh City, Da Nang, Quang Ninh, Da Lat, Buon Ma Thuat, Bac Giang and Phan Rang (Hoa and Viet-Anh, 2013) with about 24 existing centralised wastewater treatment plants (the total capacity of is about 670,000 m3/day) (Tien, 2013). However, in recent years a large number of decentralized wastewater treatment plants have been constructed in both large and medium-sized urban areas such as Hanoi, Bac Ninh, Vinh and Can Tho under support from the Vietnam Government and a number of international organizations. The amount of treated urban wastewater accounts for 10% of the total generated amount of wastewater (Nguyen Viet Anh, 2008). Many sewage treatment plants have not realized their full capacity due to a lack of sewer networks. For example, North Thang Long-Van Tri WWTP was designed and constructed with a capacity of 42,000 m3/day but in reality the plant only operated at the capacity of 7,000 m3/day as the domestic wastewater from the surrounding residential areas have not yet been connected to the plant due to a reason that the sewer networks have not been fully covered in the area (WEPA & IGES, 2013).

Similar situations have been reported in Phu Ly WWTP in Ha Nam province and a WWTP in Vinh-Nghe An province (World Bank, 2013).

Regarding wastewater treatment technologies at centralized treatment plants, the most common technologies are based on activated sludge (AS) process, such as aeration tanks or sequencing batch reactors (SBR); for example, Kim Lien & Truc Bach pilot wastewater treatment plant (WWTP), North Thang Long WWTP, Yen So WWTP, Bai Chay WWTP, Quang Ninh WWTP. In addition, there are a number of wastewater treatment plants utilising low-cost and environmentally sound sanitation technologies, such as waste stabilisation ponds or constructed wetlands. Examples of these are the WWTPs in Ho Chi Minh City (Binh Hung Hoa WWTP), Da Nang and Buon Ma Thuot.

Concerning on decentralised wastewater treatment technologies, basically, activated sludge based-treatment process and biological filtration are among the most commonly used. Recently, a new type of septic tank has been introduced, namely baffled septic tank, sometimes it has been used in combination with waste stabilisation pond or constructed wetland system. These technologies have been applied in a domestic wastewater treatment plant in Kieu Ky commune of Hanoi, WWTP at Thanh Hoa Pediatrics Hospital, WWTP in small towns in Vietnam such as Minh Duc in Hai Phong city, An Bai in Thai Binh and Cho Moi in Bac Can. Currently, there are no exact figures or data on the total number and capacity of decentralised wastewater treatment plants in Vietnam; however, it has been estimated that several thousand decentralised wastewater treatment plants, excluding septic tanks, have been constructed and installed across the country (Viet-Anh, 2010) for the purpose of treating domestic wastewater from residential areas, hospitals, hotels and office buildings.

3.2 Waste and wastewater management in Hue

3.2.1 General description of Hue

Hue is the capital city of Thua Thien–Hue Province, Vietnam. Hue is located in the central of Vietnam, which is 675 km far from Hanoi in the North and 1,060 km far from Ho Chi Minh City in the South. Between 1802 and 1945, it was the imperial capital of the Nguyen dynasty. And from 2005 till now, it became the type 1 urban of Vietnam and belongs to the Central region key economic area.

Hue city covers an area of 71.7 km^2 of area, and is located in the Perfume river basin. The river slices the city into two parts: an ancient northern half protected by an imperial fortress known as the Citadel, and a southern residential half known as the New City. The river is also the main source of water supply for Hue people.

Hue features a tropical monsoon climate with high temperatures, plentiful of radiation, and distinctive rainfall regime. Hue is one of the areas which have the highest rainfall in Vietnam. The average rainfall amount was over 2.700mm. There are two seasons in Hue city: dry season and rainy season. Dry season is from February to July. Rainy season is from August to January, and accounted for 70% the total rainfall amount of the year. The highest rainfall is in November, which accounts for about 30% the total annual rainfall. The annual average temperate is 25^0C, the hottest time in the year is from May to August (the highest temperature got 40^0C) and the coldest is from December to February (the lowest temperature got 10^0C). Average sunshine hour is 5.7 hour/day. Annual average air humidity is 86.7% (Thua Thien Hue Statistical Office, 2013).

Hue comprises 27 administrative divisions, including 27 wards with a total population of 352,046 in 2014. Population density was 4,910 people/km^2 (Hue Statistical Office, 2014). The population density has been increasing year by year due to Hue city's increasing urbanization.

The GDP per capita in 2013 was 1448 US/cap/year. The city's GDP in 2013 increased by 107.93% as compared to 2012, which showed the positively change of the social-economic conditions of Hue city (Hue Statistical Office, 2014). The economic structure of the city is oriented to dramatically increase and maintain the proportion of the industry, handicrafts, construction and trade, services, tourism, and reduce the proportion agriculture, forestry, and fishery. In 2013, contribution of services, industry and construction, and agriculture, forestry and fishing were 56.05%, 38.82%, and 9.86%, respectively (Hue Statistical Office, 2014)

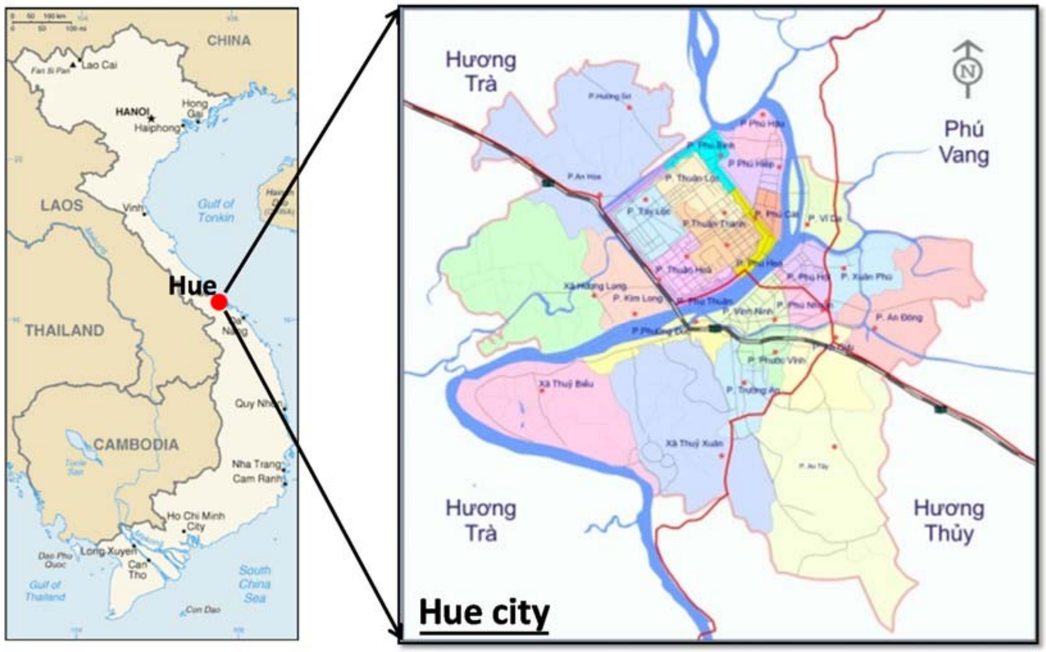

Figure 3-4 Map of Hue city (Hue city government, 2016)

3.2.2 Water supply and sanitation facilities in Hue

The public water supplied to Hue city is totally taken from Perfume River by Thua Thien Hue Construction and Water Supply company (HUEWACO). The distribution coverage of HUEWACO in Hue city is 100% of city area (HUEWACO, 2013) and 100% of household are accessible to public water (HUEWACO, 2014). Public water are used for all people daily acticites (drinking, cooking, bathing, laundry, house cleaning, gardening, *etc.*) with the average water consumption was 120-140 L/cap/day (Lieu, 2012). An initial survey conducted by Geologic Association 708 (under Vietnam's Geologic Feferation) showed that ground water reserve in Hue city is not considerable (Sanicon, 2011). The percentage of households using water from dug well and drilled wells for drinking and other domestic uses are 2.18% and 0.82%, respectively (SaniCon, 2011). Some households are using public water and others such as rain water, surface water, water from dug or drilled wells, *etc.* at the same time. However, the latter water is mainly used for gardening, laundry and cleaning (SaniCon, 2011). Besides, there is a number of households using bottled water for only drinking purpose.

According to SaniCon (2011), 95.2% of household in Hue city access to toilet facility, in which, more than 90% are flush toilet (17.4% pour flush toilet, 82.6% cistern flust toilet), and only about 3.4% are the dry ones (2.6% double vault latrine, 0.8% pit latrine) (**Table 3-2**). Most of toilet waste are discharged into septic tank (86.7% of the whole population), the rest come to sulabh (4.5%) and pit or vault (3.4%). Toilet waste was not used for agriculture in the city.

Table 3-2 Distribution of toilet types in Hue city (SaniCon, 2011)

Type of toilet	**%**
Pour flush toilet	51.2
Cistern flush toilet (1 flush mode)	15.9
Cistern flush toilet (2 flush modes)	24.1
Double vault latrine	2.6
Pit latrine	0.8
No toilet	0.6

3.2.3 Domestic solid waste and septage management in Hue

The generation rate of domestic solid waste is about 0.72 kg/cap/day (250 ton/day) (HEPCO, 2013). Degradable organic wastes accounted for 75% of the total wastes. Hue Urban Environment and Public Works State Company (HEPCO) is responsible for collection, transportation, and treatment of the city's solid waste. At present, the collection ratio of solid waste is 95% in central urban areas (HEPCO, 2013). The collection method is mainly using carts to collect solid waste from households, shops, *etc.* and public wastebasket, then, transport to the transit station and finally transport to Thuy Phuong sanitary landfill (belongs to Thuy Phuong commune, Huong Thuy district, 12 km far from the city center, 10 ha of area) by trucks. Partly of collected waste is recycled at the Thuy Phuong Waste Processing Plant to make plastic goods (pipe, bucket, *etc.*), inorganic construction materials (*e.g.* bricks), and composting products. The remaining is sent to the landfill.

Septage is collected mainly by HEPCO. There are some small private companies conduct the collection, but the number of the companies has not been known yet. Total septage amount collected by HEPCO is 1.973 ton/day (9.978 m^3/year) (Sanicon, 2011). Septage collected by HEPCO is transported to Thuy Phuong sanitary landfill to treat together with solid waste (HEPCO, 2013).

3.2.4 Drainage network and domestic wastewater management in Hue

Hue city is using a combined sewer system for the collection of both municipal wastewater and storm water. The system, with a total length of 199 km, is composed 132m concrete pipes (diameter from 400mm-1200mm), 67m rectangular culverts (width from 300mm-800mm), and 9.031 manholes (typical size 1m x 1m) (HEPCO, 2013). The system is operated under the principle of gravity, without pumping stations. Surface water runoff and waste water are collected and flow in the pipe lines system and then directly pour into the river, or lakes. The area of city covered with sewer system is about 40% (HEPCO, 2013). However, the coverage of sewer system is mainly at more developed wards in the center of the city. The coverage ratio in Hue is similar to the average coverage of Vietnam (40-50%), but is lower than that in large urban such as Hanoi (70%). A large portion of wastewater is directly discharged into surface ground (home garden, road, *etc.*) and water bodies (rivers, lakes, *etc.*). According to the master plan of sewerage and drainage system of Hue city, the coverage of sewer system will be 100% by 2020 (Thua Thien Hue PPC, 2007).

Presently, Hue city does not have any treatment plants for domestic wastewater treatment. Wastewater was discharge directly to the environment. A small portion of domestic wastewater is pretreated by septic tanks or simple settling tanks and then discharged into environment. A project "Hue City Water Environment Improvement", which is financially supported by JBIC, is implementing to enhance the city's sewage treatment capacity and reduce flood damage by improving the sewerage and drainage systems. The project is divided into two phases. The 1st phase is from 2008-2016, which targets to the southern part of the city and includes the construction of a municipal wastewater treatment plant with capacity of 20,000 m^3/day. The 2nd phase will be implemented for the city's northern part, and upgrade the capacity of the plant in southern part to 40,000 m^3/day (SaniCon, 2011).

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Chapter 4 Characterization of a combined sewer discharge in a residential drainage area in Hue, Vietnam

4.1 Introduction

The expansion of urban populations, increase of coverage of domestic water supply, and other changes in lifestyles in urban areas in developing countries have made the increase of waste and wastewater amount and the change of material flows through urban areas greatly. Ineffective management of water and other material flows has led to the increase of both surface and ground water pollution. Since domestic sewage discharge potentially has impacts on the overall material flow in urban areas, a well understanding of its characteristics might help in finding a better management of material flows and thus could make a contribution in the improvement of urban environment. Adequate data of wastewater characteristics is considered as one of key factors for a successfully wastewater management (UN, 2015).

Information on domestic wastewater characteristics are readily available in developed countries (Kafi *et al.*, 2008; Sandoval *et al.*; 2013, *etc.*). However, it is the opposite case in developing countries where sewerage systems are incomplete and poorly managed. At present, data in all aspects of wastewater in developing countries is still very poor, inadequate or outdated (Sato *et al.*, 2013). Some studies on domestic wastewater were conducted in developing countries. However, most of these studies focused on investigating physico-chemical characteristics of domestic wastewater (Sonune *et al.*, 2015, Tsuzuki *et al.*, 2010, *etc.*). The amount of wastewater discharge was often estimated by using the average value of water consumption. Meanwhile, wastewater flows and composition are not steady or uniform, but vary throughout the day (hourly variations), during the week/month (daily variations) and throughout the year (seasonal variations) (Von Sperling, 2007). These variations are very important that need to be investigated in order to obtain accurately representative data, which is very essential for an effective and economical wastewater management program. Recently, there were some studies investigated the variations of wastewater flow rate and pollutants concentration in Pakistan (Haider and Ali, 2012), Kuwait (Almedeij and Aljarallah, 2011), and Romania (Popa *et al*., 2012). These studies have provided more information on the fluctuation of domestic wastewater discharge. However, these information was not enough to be a representative for all urban areas in developing countries since wastewater characteristics are also greatly different among places because of the differences in the behavior, lifestyle and standard of living of the inhabitants, *etc*. More studies on domestic wastewater characteristics and it fluctuation should be conducted for other areas. From that, a representative characteristics and pattern of wastewater discharge will be obtained and classified for each type of urban areas.

The objectives of this chapter were to characterize the domestic sewage discharge, focusing on quantity and quality fluctuations over time in a residential area in urban Hue city, Vietnam. From that, pollution loads from the sewer system were estimated and the relationship between flow rates and pollution loads were also identified.

4.2 Materials and methods

4.2.1 Study site

The study area is a residential drainage area in Thuan Thanh ward, Hue Citadel, Hue city, Vietnam, as shown in **Figure 4-1**. The area covered 11.2 ha, of which 70% had impervious surface (CIT, 2013). The population of the drainage area was 1,452, distributed in 363 households in 2015 (People's Committee of Thuan Thanh ward, 2015). Average water consumption was estimated as 134 L/cap/day in 2013 (HUEWACO, 2013). Domestic wastewater was collected by a combined sewer system or discharged directly to ground surface or water bodies. The sewer system played a role in conveying domestic wastewater and storm water from study area to water bodies. The sewer network was composed of 836 m open ditch; 1,992 m sewer and 124 manholes (HEPCO, 2013). Sewer pipes were made of concrete and buried at 700 mm depth from the surface road. Average sewer slope was 0.4% (JICA, 2006). 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 (HEPCO, 2013).

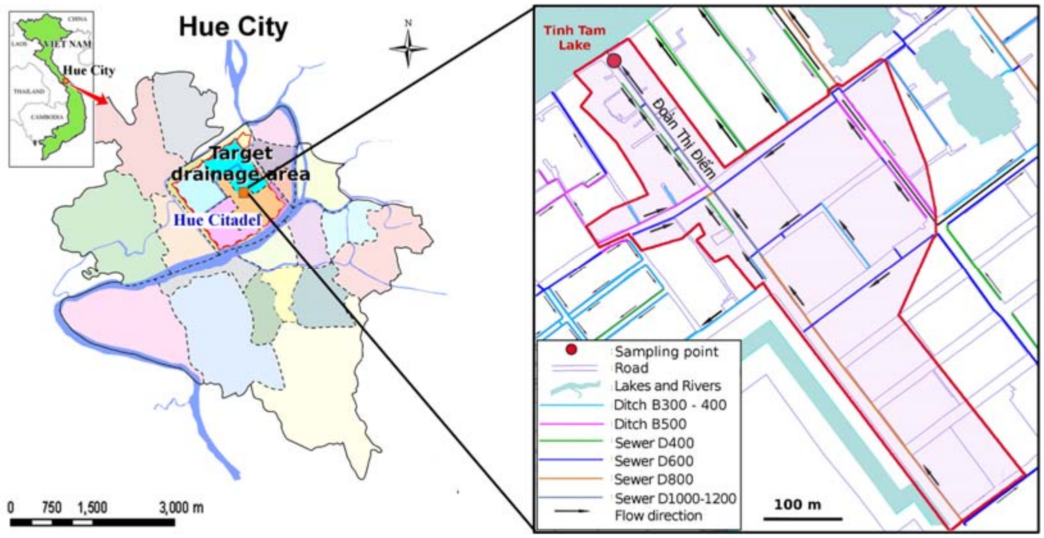


Figure 4-1 Target drainage area (HEPCO, 2013)

4.2.2 Household water consumption survey

Hourly water consumption survey

Water consumption amounts were recorded hourly during 24 hours on four days in July 2015 (the same days with flow rate survey in dry season: 18^{th}, 25^{th}, 22^{th}, and 23^{th}) for each of household based on a water meter of each household. Before recording water meters, we conducted an interview for all household in the target drainage area to check the accessibility of water meter in 24 hours such as location of water meter, their permission to access water meter for recording, *etc*. In total 23 households allowed us to access their water meters.

Monthly water consumption data collection

Data on one-month water consumption in July 2015 of 308 households in the target drainage area was supplied by Thua Thien Hue Construction and Water Supply State Co., Ltd (HUEWACO) (HUEWACO, 2015).

4.2.3 Household wastewater management survey

A structured interview survey was conducted for households in the target drainage area in July 2015 to obtain information on household wastewater management in 2015. Expected result was to determine the ratio of household discharges their greywater and septic tank effluent into the sewer system. Sample size was determined based on Yamane’s formula at 95% confidence level (Yamane, 1967):

$$n = N/(1 + Ne^2) \qquad \textbf{(Eq. 4-1)}$$

Where n: sample size (number of interviewed household);

N: population size (total number of household in target drainage area – 1,452);

e: acceptable error (0.1) .

Since n is calculated as 93.6, the sample size of this study was determined to be 100. The households to be interviewed were randomly selected. Main contents of the interview were shown in **Table 4-1**. Details of the questionnaire are shown in **Appendix I (A)**.

Table 4-1 Main contents of the structured interview

Item	**Content**
Household attributions	Size, age structured, occupation, income, *etc.*
Water use and sanitation facilities	Water sources, water use facilities, toilet types
Greywater management	Main source of greywater (from household/business activities?) Discharged into sewer system or anywhere else?
Toilet effluent management	On-site sanitation system types? Desludging experience? Influence to septic tank (greywater/toilet waste)? Discharged into sewer system or anywhere else?

4.2.4 Sewer outlet discharge survey

Sewer discharge flow rate measurement

Discharge flow rate surveys were conducted at the sewer outlet on dry days in dry season 2015 and rainy season 2015 and 2014; and on rainy days in rainy season 2015. On dry days in dry and rainy season 2015, flow rate was monitored hourly in 24 hours of each day. On dry days in rainy season 2014, flow rate was monitored hourly from 7:00 to 21:00 of each day. On rainy days, discharge flow rate were measured during the time rain occurred (from the time rain started to the time rain stopped). In the first two hours of rain, the measurement was conduct with 20-minute interval. And from after two hours of rain until the rain stopped, the measurement was conducted with 1-

hour interval. Moreover, flow rate at 1 - 2 hours before and after rain were also checked with 1-hour interval. Detail information of discharge flow rate survey days were summarizes in **Table 4-2**.

Table 4-2 Description of sewer outlet discharge survey days

			Discharge flow rate survey					Discharge quality survey
Season	**Year**	**Date**	**Weekday / Weekend**	**Weather condition**	**Antecedent dry period (day)**	**Duration time of measurement**	**Frequency of measurement**	
Dry season (Feb.-Jul.)	2015	18 Jul.	Sat.	Dry	2	24 hours	1 hour	X
		25 Jul.	Sat.	Dry	4	24 hours	1 hour	X
		22 Jul.	Wed.	Dry	1	24 hours	1 hour	X
		23 Jul.	Thu.	Dry	2	24 hours	1 hour	X
Rainy season (Aug.-Jan.)	2015	16 Nov.	Mon.	Dry	5	24 hours	1 hour	X
		26 Nov.	Thu.	Dry	1	24 hours	1 hour	
		4 Dec.	Fri.	Dry	4	24 hours	1 hour	
		5 Dec.	Sat.	Dry	5	24 hours	1 hour	
		24 Nov.	Tue.	Wet	2	During raint event	20 mins - 1 hour	X
		27 Nov.	Fri.	Wet	2	During raint event	20 mins - 1 hour	X
		29 Nov.	Sun.	Wet	0	During raint event	20 mins - 1 hour	X
		6 Dec.	Sun.	Wet	6	During raint event	20 mins - 1 hour	X
	2014	1 Nov.	Sat.	Dry	0	7:00-21:00	1 hour	X
		2 Nov.	Sun.	Dry	1	7:00-21:00	1 hour	
		10 Nov.	Mon.	Dry	0	7:00-21:00	1 hour	
		19 Nov.	Wed.	Dry	3	7:00-21:00	1 hour	X
		21 Nov.	Fri.	Dry	0	7:00-21:00	1 hour	
		14 Nov.	Sat.	Wet	0	7:00-21:00	1 hour	
		22 Nov.	Sat.	Wet	1	7:00-21:00	1 hour	

A V-notch weir (90° angle) was used for the measurement of discharge flow rate (**Figure 4-2**). The weir was made from galvanized black iron with a rubber layer at the edge and was installed inside the sewer pipe at the location near the outlet (50 m) of the sewer system. The weir was installed perpendicular to the flow using wooden struts and sealed by artificial clay to fix and to prevent water penetrated at the edge (**Figure 4-3**). Head of the weir (*H*) was read and then, the sewage flow rate was calculated using equations.

On dry days in dry season (with $H \leq 0.07$m), the equation for calculating flow rate was as follows:

$$Q = 3600 \times 2.1 \times H^{2.6} \qquad \textbf{(Eq. 4-2)}$$

Where: Q: the discharge over the weir (m^3/h);

H: the head of the weir (m);

3600: conversion factor from second to hour

This equation was established by our actual measurement. Heads of the weir were recorded. At the same time, volume of the water flowing over the weir was also measured by a bucket and the time to fill a bucket was recorded. From that, flow rates over the weir were calculated. The measurement was carried out at 1 hour – 2 hour interval during 24 hours on a dry day. From flow rates (*Q*) and the corresponding heads of the weir (*H*), **Equation 4-2** was obtains.

On rainy days, since **Equation 4-2** was not suitable for flow rate calculation at the high values of H (H > 0.07m), flow rate was calculated by a modified Cone equation (USBR, 1997):

$$Q = 3600 \times 5.0 \times H^{2.5} \qquad \textbf{(Eq. 4-3)}$$

Where: 5.0 was the optimized value of head correction factor with the assumption that 65% of runoff water came to the sewer system.

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 accumulation of sewage by using the weir. Therefore, a calibration was made by taking into accounts the stored water in sewer pipes with the consideration of sewer slope to estimate the actual flow rates.

Figure 4-2 A 90°V-Notch weir

Figure 4-3 Installation of the weir into sewer pipe for flow rate measurement

Sewer discharge quality analysis

Sewer discharge quality surveys were conducted on dry days in dry season 2015, rainy season 2015 and 2014; and on rainy days in rainy season 2015 (**Table 4-3**) .The sampling was conducted at the same time with discharge flow rate survey.

On dry days in rainy season 2014, samples were collected from 7:00 to 21:00 of each day with 6-hour interval (7:00, 11:00, 16:00 and 20:00). On dry days in dry season and rainy season 2015, the sampling was conducted in 24 hours in each survey day with 1-hour interval, started at 1:00. Then, SS and VSS were analyzed with 1 hour-interval sample; COD_{Cr}, TN, NH_4^+ and TP were analyzed with 2-hour interval sample; and BOD_5 were analyzed with 4-hour interval sample (**Table 4-3**). On rainy days in rainy season 2015, samples were collected 1-2 hours before the rain started, during the time rain occurred, and 1-2 hours after the rain stopped. In the first two hours of rain, the sampling was conduct with 20-minute interval. From after-two hours of rain until the rain stopped, the sampling was conducted with 1-hour interval.

After sampling, all samples were contained in a bottle without headspace, preserved with ice, and transported to laboratory to analyze by the Standard Methods (APHA, 2005). All samples were analyzed in both total phase (without filtration) and dissolved phase (with filtration, using WHATMAN glass fiber filter paper with pore size 1.0 µm), and then, particulate concentrations were determined by the difference of the two above concentrations.

Temperature (T°), pH, and electrical conductivity (E.C.) of samples were also measured on-site by portable meters (B-711 LAQUAtwin Compact pH Meter, and B-771 LAQUAtwin Compact Conductivity Meter, Horiba) (**Figure 4-4**).

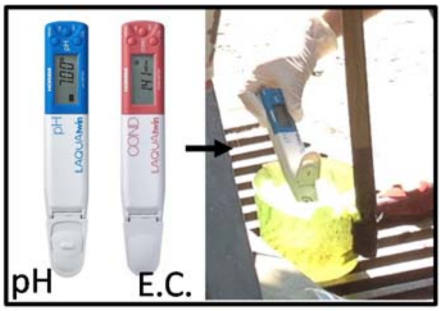


Figure 4-4 Portable meters

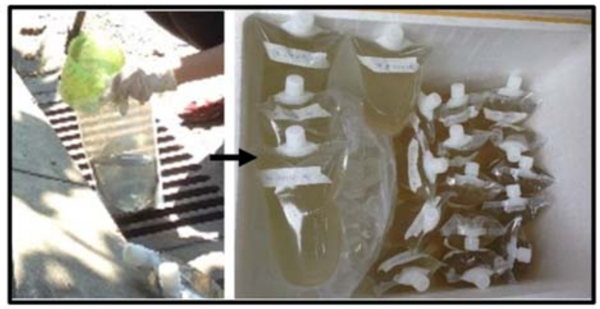


Figure 4-5 Sewage samples

Table 4-3 Description of sampling time and analytical parameter on dry days

Sampling time	1:00	2:00	3:00	4:00	5:00	6:00	…	22:00	23:00	24:00	1:00
Analysis	*	*	*	*	*	*	…	*	*	*	*
	**		**		**		…		**		**
	***				***		…				***

Note: (*) pH, E.C., T^0, SS, VSS

(**) Total and dissolved concentrations of COD_{Cr}, NH_4^+, TN, TP

(***) Total and dissolved concentrations of BOD_5

Rainfall intensity measurement

During the time of sewer discharge survey, rainfall amount was measured by an automatic rain gauge (includes a bucket rain gauge (AN-011) and a recorder (ARF-3), Ltd. Ando Keiki Kosho). The bucket rain gauge was installed on the roof of a house located near the sewer survey site. The rain gauge was set up at 10 minutes interval measurement mode.

(a) Rain gauge (b) Installed on the house's roof (c) Recorder connected with PC

Figure 4-6 Rainfall measurement

4.2.5 Pollution load estimation and its relationship with flow rate determination

Pollution load from sewer discharge in the target drainage area was calculated as follows:

$$L_i = \frac{(C_{i,1} \times Q_1 + C_{i,25} \times Q_{25})}{2} + \sum_{t=2}^{24} C_{i,t} \times Q_t \qquad \textbf{(Eq. 4-3)}$$

Where L_i: the total load of parameter *i* (g/day);

$C_{i,t}$: the concentration of parameter *i* at time *t* (g/m^3);

Q_t: the corresponding discharge flow rate at time *t* (m^3/h).

Then, *L*-*Q* equations were established for each parameter to understand the relationship between discharge flow rates and pollution loads:

$$L_i = kQ^n \qquad \textbf{(Eq. 4-4)}$$

Where *Li*: the load of parameter *i* (g/h);

Q: the discharge flow rate (m^3/h);

k, *n*: parameters derived after regression fitting.

4.3 Results and discussions

4.3.1 Water consumption pattern

Figure 4-7 shows the pattern of water consumption in a day on four days of 23 households in the target drainage area. Water consumption patterns were rather similar on four days (P>0.05) (ANOVA table is shown in **Appendix I (F1)**). Two peaks of water consumption were observed in the morning (from 4:00 - 10:00) and evening (14:00 - 24:00), and a small peak was observed at noon (from 10:00 – 14:00). The highest water consumption was found at 7:00 - 8:00 and 19:00 – 21:00. There was very low water consumption at early morning (1:00 – 4:00). This pattern reflected exactly the lifestyle in urban Hue. In Hue, people often go to work from 8:00 – 12:00 and from 1:00 – 5:00. In the morning, a large amount of water was consumed for hygiene (bathing, toilet use) and breakfast preparation before they go to work. At noon, a majority of people came back home for lunch and taking a rest. At late afternoon and evening, people came back home again and continued consuming a large amount of water for bathing, cooking, and washing.

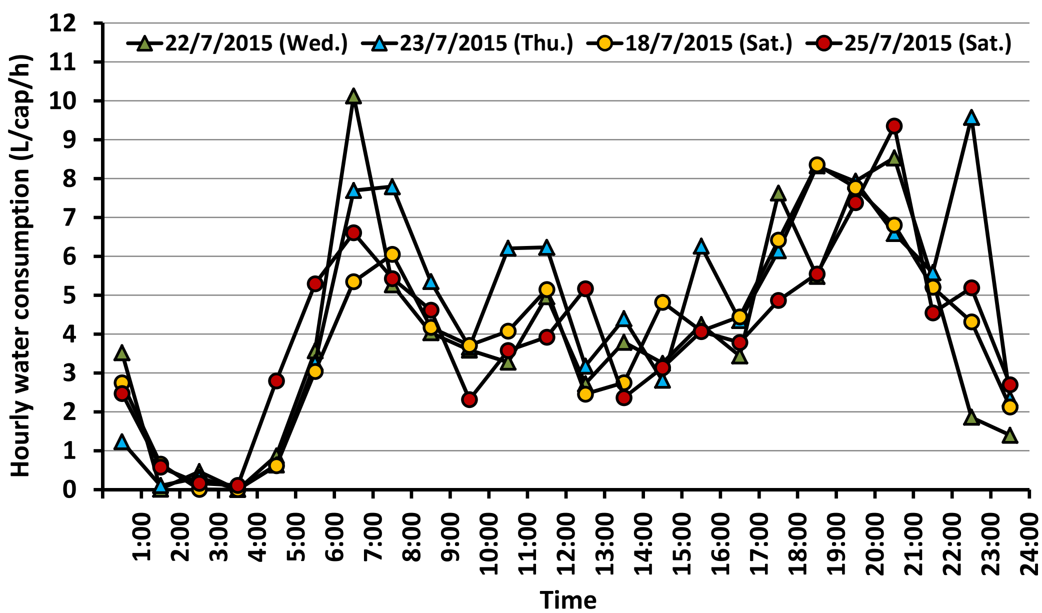


Figure 4-7 Average hourly water consumption in 24 hours on 2 weekdays and 2 weekends of 23 households

The water consumption pattern in Hue rather similar to a typical diurnal pattern of water consumption in an urban area (Cole, 2011) (**Figure 4-10**) as well as the diurnal pattern in Queensland, Australia (Cole and Steward, 2012) (**Figure 4-9 (b)**) and in North America (Mayer and DeOreo, 1999) (**Figure 4-9 (c)**) with 2 peaks in the morning and evening. There were some small differences which reflected the difference in life style between Hue city and other areas. The highest peak of water consumption in Hue city occurred a bit earlier than that in other areas (7:00-8:00

compared to 8:00-9:00), which is easy to understand since people in Hue city get up and go to work earlier than others. Besides, the water consumption pattern in Hue has a small peak at noon. This was because a large number of people in Hue often come back home to have lunch while people in other areas often have lunch at the offices. Water consumption trend in Hue was rather different with that in urban Spain (Gascón *et al.*, 2004) (**Figure 4-9 (d)**).

Compared to Hanoi, Vietnam, Hue city had a quite similar water consumption trend with 3 peaks of water consumption in the morning, noon and evening (Anh, 2014) (**Figure 4-9 (a)**). However, the evening peak was the dominant compared to the remaining two peaks. The evening peak in Hanoi (from 18:00 – 24:00) was also started a bit later than in our study site and easy to be separated with previous time, while the evening peak in our study site started sooner (14:00 – 24:00). It can be explained by a part of people in our area have their work conducting at home such as home-based business, retired, housewife, *etc.* and consumed water on the whole day.

There was no difference in water consumption between weekdays and weekends (P>0.05) (ANOVA table is shown in **Appendix I (F1)**), which indicated that there was no special consumption activities conducted on weekends in this survey.

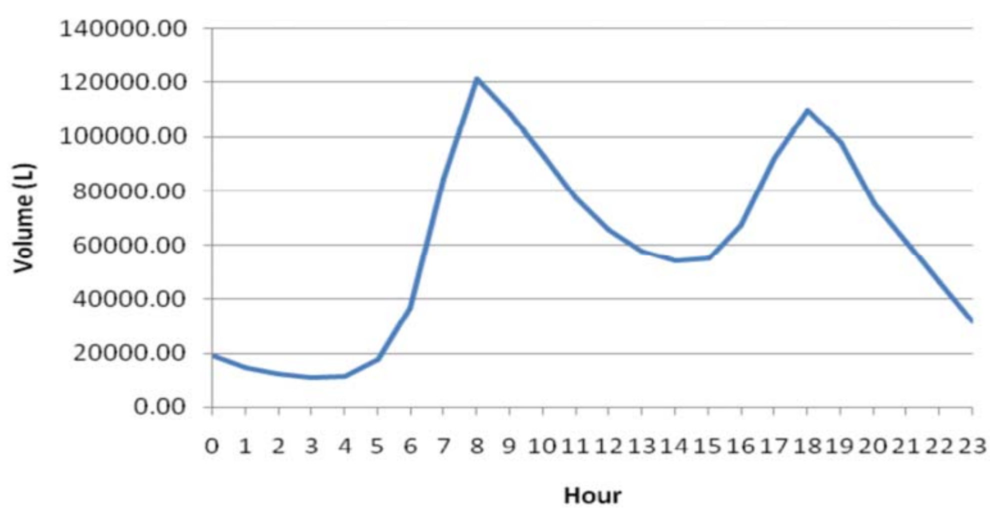
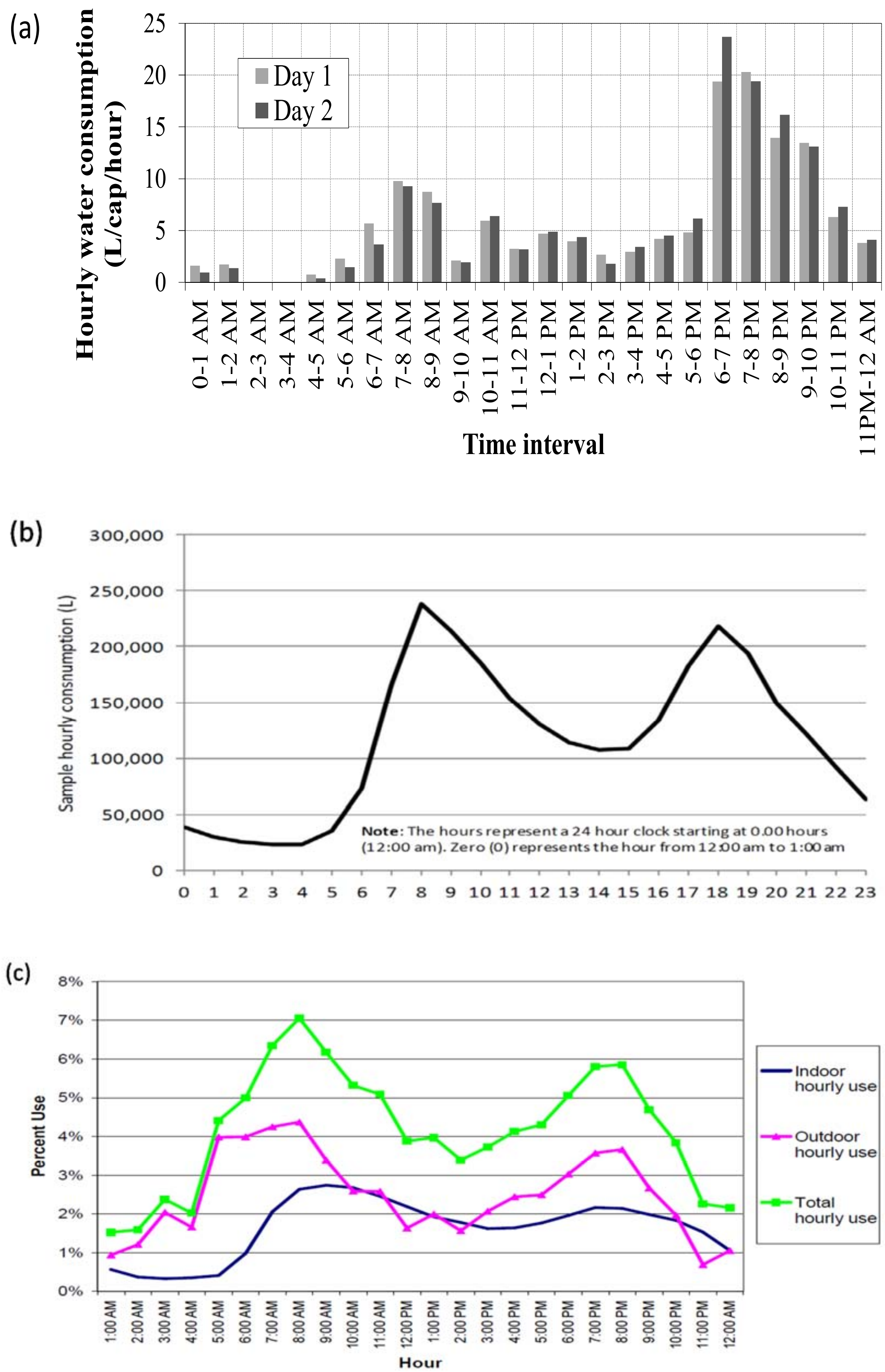


Figure 4-8 A typical diurnal pattern of water consumption in an urban area (Cole, 2011)


(a)
Hourly water consumption (L/cap/hour)
Day 1
Day 2
0
5
10
15
20
25
0-1 AM
1-2 AM
2-3 AM
3-4 AM
4-5 AM
5-6 AM
6-7 AM
7-8 AM
8-9 AM
9-10 AM
10-11 AM
11-12 PM
12-1 PM
1-2 PM
2-3 PM
3-4 PM
4-5 PM
5-6 PM
6-7 PM
7-8 PM
8-9 PM
9-10 PM
10-11 PM
11PM-12 AM
Time interval
(b)
Sample hourly consnumption (L)
0
50,000
100,000
150,000
200,000
250,000
300,000
Note: The hours represent a 24 hour clock starting at 0.00 hours (12:00 am). Zero (0) represents the hour from 12:00 am to 1:00 am
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
(c)
Percent Use
0%
1%
2%
3%
4%
5%
6%
7%
8%
Indoor hourly use
Outdoor hourly use
Total hourly use
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
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11:00 PM
12:00 AM
Hour

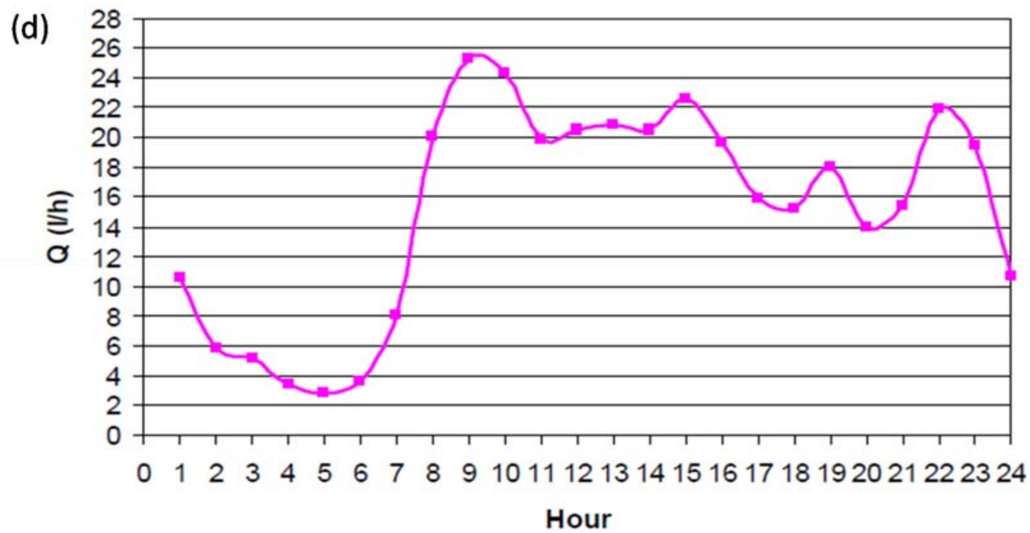

Figure 4-9 Diurnal pattern of average hourly consumption in Hanoi, Vietnam (Anh, 2014) (a); in Queensland, Australia (Cole and Steward, 2012) (b); in North America (Mayer and DeOreo, 1999) (c); and in Spain (Gascón *et al.*, 2004) (d)

4.3.2 Domestic wastewater management in a residential drainage area in urban Hue

In urban Hue, wastewater was discharged into the sewer systems, surface ground or water bodies. Houses located in the area which could access with sewer system discharged their wastewater into the system. The houses in the area that were not connected to the sewer system discharged wastewater directly to the environment. Those living in small lanes utilized nearby vacant land or a simply constructed canal or channel for direct discharge of wastewater to the ground at a distance from their houses. For the households close to the lake direct discharge of wastewater to these open water bodies usually occurred. Greywater was not reused for any purposes.

Greywater and toilet effluent flows in the study site were described in **Figure 4-10**. Nighty-four percent of households discharged their greywater directly (58%) to the sewer system or indirectly through a manhole (36%). This ratio was very higher than that in Hue Citadel (52%) (Anh *et al.*, 2016) or Hue city (40%) (HEPCO, 2013). This was because of the high coverage of sewer system in the selected drainage area. Only a small number of households discharge their grey water into the environment (5% to surface ground and 1% to Tinh Tam Lake).

Seventy-one percent of households used septic tanks as on-site sanitation systems, the remaining (29%) used cesspools. The ratio of septic tank connections in the area was slightly lower than that in urban areas of Hanoi (90%) (Harada *et al.*, 2008) and Da Nang (80%) (Quang, 2010) in Vietnam, and Metro Manila in the Philippines (85%) (AECOM International Development, Inc. and Eawag-Sandec, 2010). It was also found that 35% of septic tanks in this area had desludged in the past with desludging intervals of 10±6 years (Avg.±S.D.). According to a recommendation from the U.S. Environmental Protection Agency (2000), a septic tank should be desludged every two to five years to recover its performance. However, only 36% of the already desludged septic tanks in this study met the criterion due to poor management, which led to poor performance.

Compared to greywater connection, the ratio of septic tank effluent connected to sewer system was lower (53%). This ratio was slightly higher than that in Hue Citadel (40%) (Anh *et al.*, 2016), and Danang city (15.7%) (SaniCon, 2010), but was much lower than that in Hanoi (90%) (Harada *et al.*, 2008). Seventeen percent of septic tank effluent and 100% cesspool effluent came to underground, and 1% of septic tank effluent came to the water body.

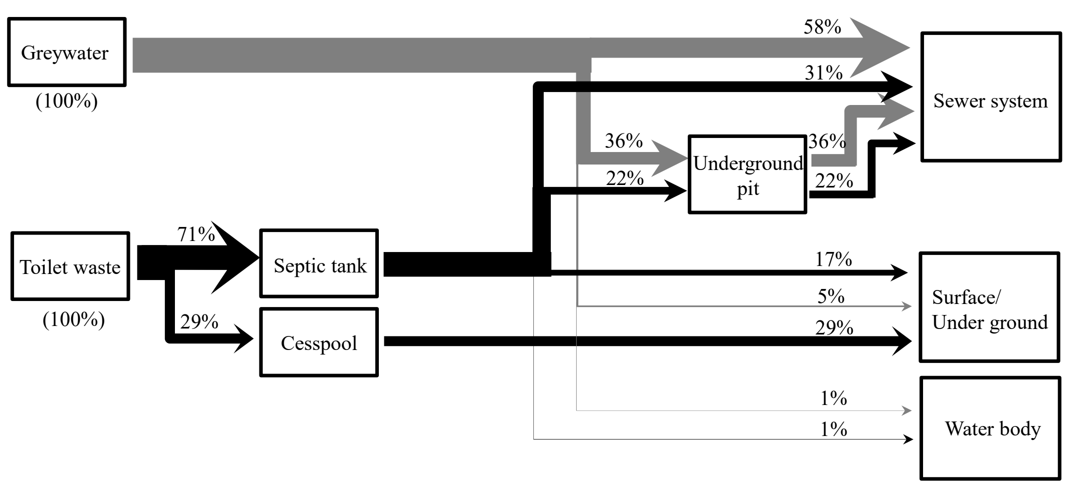

Figure 4-10 Greywater and toilet waste effluent flows in target drainage area

4.3.3 Combined sewer discharge flow rate

Characteristics of discharge flow rate on dry days

Discharge flow rates on dry days in dry season (DdDs) are presented in **Figure 4-11 (a)**. Discharge flow rate varied among hours during 24 hours in a day. Two peaks of discharge were observed from 6:00 – 17:00 and from 17:00 – 0:00. The lowest rates were observed during the early morning (1:00 - 6:00). The fluctuation of discharge flow rates in basic corresponded to the water consumption trends (**Figure 4-11 (b)**) although distinct peaks in the morning, lunch time and evening were not clearly observed. High discharge occurred in the daytime when water consumption activities were carried out, and the lowest discharge occurred in the time when water consumption was lowest due to people went to sleep. The less fluctuation of flow rate compared to water consumption trend might be because the transportation of wastewater from all points in a large upstream area to the final sewer outlet probably harmonized the peak of flows. A study on wastewater in Hanoi (Anh *et al.*, 2014) which measured the discharge flow rates directly at the outlet of a discharging pipe from individual house buildings demonstrated more clearly the resemblance between household wastewater discharge and water consumption pattern.

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.* (2004) (**Figure 4-11(c)**). The only difference in the two patterns was that the first peak of discharge in Tchobanoglous *et al.* (2004) was higher than the second peak while these peaks in our study area were quite equal. It might be due to the difference in the water consumption behavior style. Water consumption amount in the morning and evening in our study area were rather similar.

On dry days in rainy seasons (DdRs), discharge flow rate variably changed among hours in a day without any rules of pattern **Figure 4-12 (a), (b)**. Discharge flow rates on DdRs were lowest in the early morning (1:00 – 6:00), which were similar to those on DdDs, but was rather higher than those at the same time on dry days.

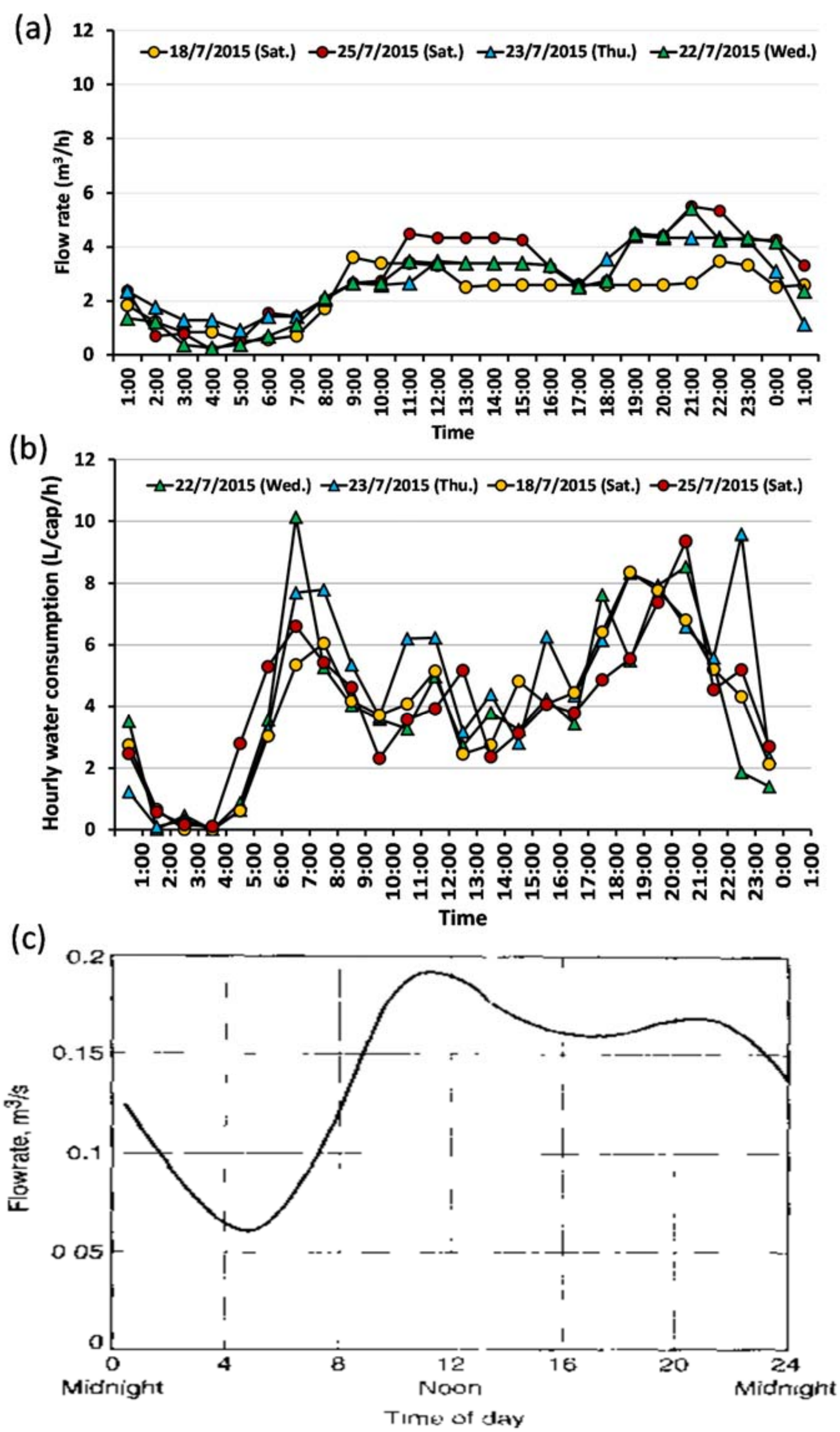

Figure 4-11 Hourly discharge flow rates at sewer outlet on dry days in dry season 2015 (a), average hourly water consumption (b), and hourly domestic WW flow rates described by Tchobanoglous *et al.* (2004) (c)

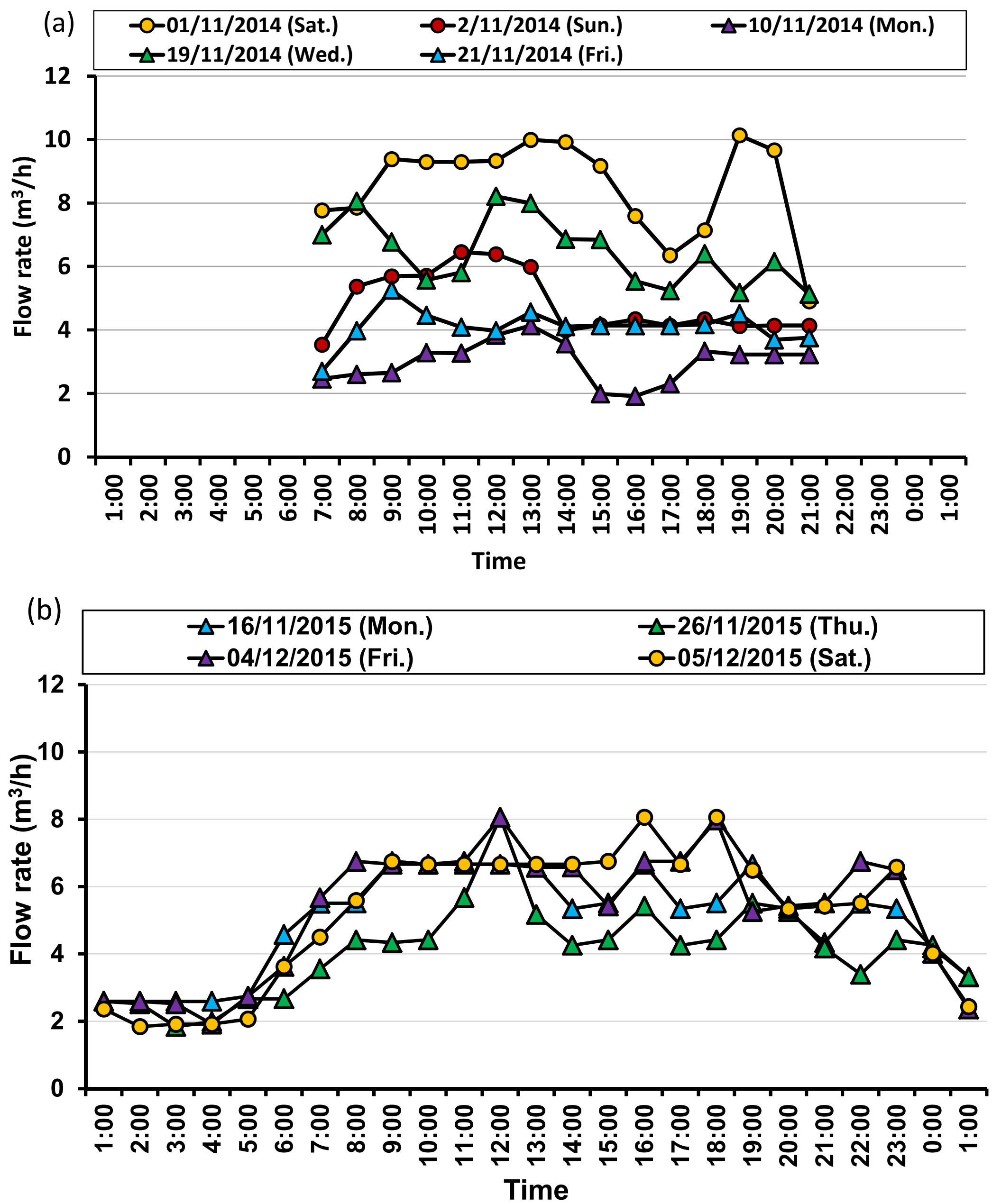

Figure 4-12 Hourly discharge flow rates at sewer outlet on dry days in rainy season 2014 (a), and rainy season 2015 (b)

The average discharge flow rate on DdDs in 2015 was 2.72±0.32 m^3/h (ave.±s.d.) (equivalent to 44.9±5.4 L/cap/day), which was about half of that on dry days in rainy season (4.99±0.55 m^3/h or 82.5±9.1 L/cap/day in 2015, and 5.38±2.15 m^3/h or

88.9±35.5 L/cap/day in 2014) (**Figure 4-13**). In dry season 2015, discharge flow rate did not show the difference in day among dry days (*P*>0.05) (ANOVA table is shown in **Appendix I (F2)**) or between weekdays and weekends (*P*>0.05) (ANOVA table is shown in **Appendix I (F2)**). In rainy seasons, especially in 2014, discharge flow rate fluctuated among dry days. However, since the observed dates were limited, the daily fluctuation of flow rate was not indicated at present. It is suggested that daily flow rate should be continuously monitored to discover the characteristic of daily discharge flow rate.

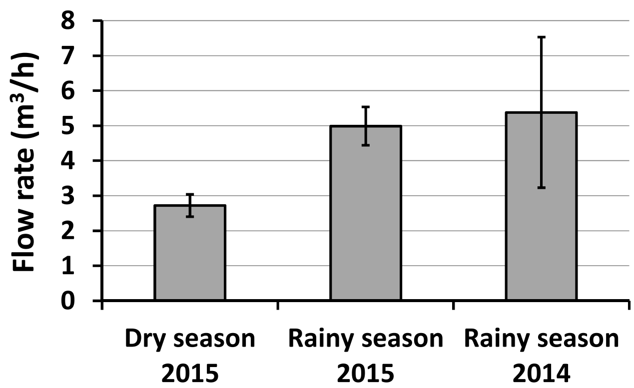

Figure 4-13 Average discharge flow rate on dry days in dry season and rainy season

Discharge flow rate in wet weather condition

Discharge flow rates on rainy days in rainy seasons are presented in **Figure 4-14**. Rainfall intensity lower than 1mm/h did not seem to cause impact on discharge flow rate, as shown on 14th Nov. 2014. With rainfall intensity higher than this level, discharge flow rate increased many time higher than dry weather discharge flow and fluctuated with rainfall intensity. Stronger rainfall intensities corresponded to a higher discharge flow rates. A slightly delay of peak timing between rainfall and sewer discharge was observed, as shown on 22nd Nov. 2014 (8:00-9:00) or 6th Dec. 2015 (11:20 – 11:40), *etc.* However, to understand more the impact of rain on discharge flow rates, more observation on discharge flow rates in different rainfall intensities should be conducted.

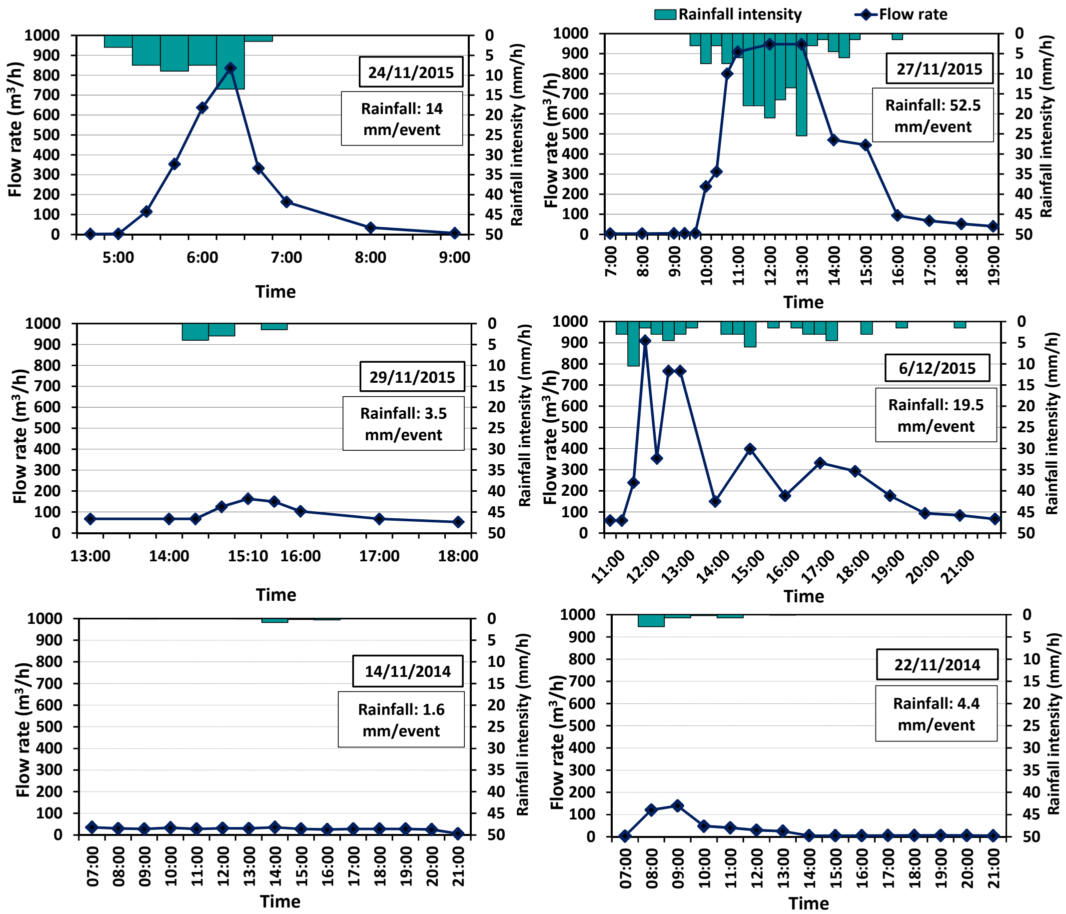

Figure 4-14 Discharge flow rates at sewer outlet on rainy days in rainy season

4.3.4 Sewer discharge quality

Discharge quality on dry days

Average discharge concentrations on dry days in both dry season and rainy season are shown in **Figure 4-15**. Low concentration of sewer discharge on dry days in both dry and rainy seasons showed that domestic wastewater in Hue city was not strongly polluted. This is probably a characteristic of domestic wastewater in urban areas in Vietnam since the wastewater quality in the influent of a wastewater treatment plan in Hanoi was also at a similar level (Nga *et al.*, 2014). Compared to other areas, except nitrogen concentration, pollutant concentrations in the sewer discharge were much lower than the influent quality of wastewater treatment plants in other Asian cities, and even weaker than a typical low strength sewage defined by Tchobanoglous *et al.* (2004) (**Table 4-4**). Especially, SS concentration of the sewage in this study was much lower than the others. This can be explained by the settling of particulate pollutants in the sewer; although 0.6-1.5 m/s is generally required for an in-sewer wastewater velocity, the value in this study was 0.009±0.003 m/s. The ratios of particulate/dissolved phase in this study on dry days in dry season were 0.2, 0.3, 0.3, and 0.2 for BOD_5, COD_{Cr}, TP and TN, respectively, whereas those at household wastewater discharge in Hanoi were 0.8, 0.7, 1.7, and 1.0 for BOD_5, COD_{Cr}, TP, and TKN, respectively (Anh *et al.*, 2014). This smaller proportion of particulate phase in this study supports our argument that in-sewer settling significantly contributed to the low strength discharge in this study. Moreover, the in sewer-settling process might occur stronger under the impact of V-Notch which reduce the flow velocity and create the condition for particulate matter settlement. Therefore, we propose to collect the wastewater sample at the forward position placement of V-Notch to prevent the impact of V-Notch on the discharge quality identification.

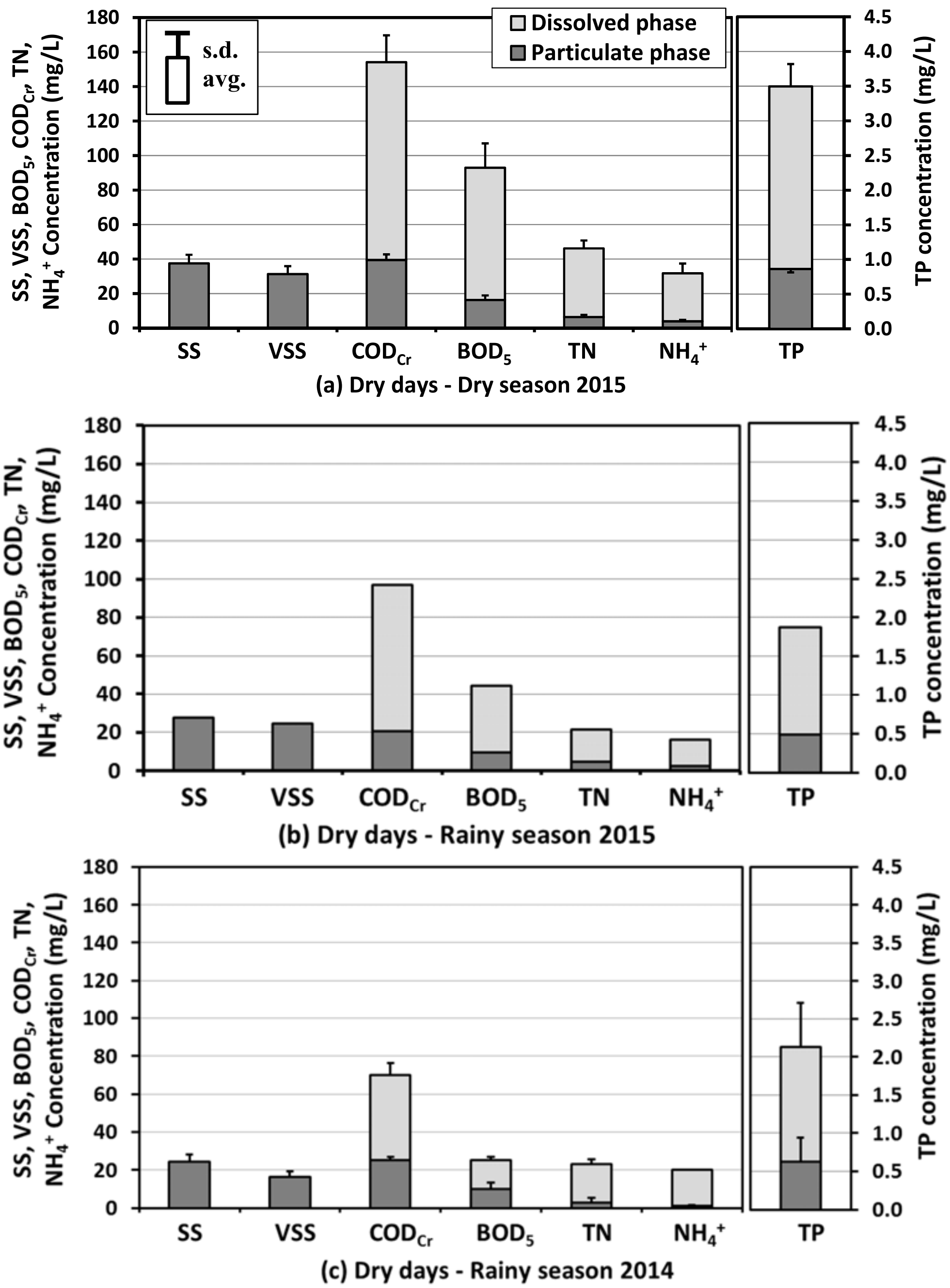

Figure 4-15 Average discharge quality at sewer outlet on dry days in dry season 2015 (a) and rainy season 2015 (b) and 2014 (c)

Table 4-4 Wastewater concentrations at the outlet on dry days in dry season and rainy season in compared with those in the influent at WWTPs in other areas

Item		At sewer outlet			At wastewater treatment plants (influent)				
		Hue - Dry season 2015	Hue - Rainy season 2015	Hue - Rainy season 2014	Hanoi - Dry season [11]	Hanoi - Rainy season [11]	Malaysia[13]	Bangkok[14]	Low strength[3]
SS	(mg/L)	37.5 ± 5.1	27.8	24.2 ± 4.1	46	45	124	60	120
VSS	(mg/L)	31.3 ± 4.6	24.5	16.2 ± 3.3	---	---	---	---	95
COD_{Cr}	(mg/L)	154.2 ± 15.7 (74.5%)	96.9 (78.6%)	69.9 ± 4.9 (64.0%)	118	109	294	---	250
BOD_5	(mg/L)	92.9 ± 15.9 (82.5%)	44.5 (79.0%)	25.4 ± 4.7 (60.6%)	47	40	135	44	110
TN	(mg/L)	46.1 ± 4.8 (86.2%)	21.3 (77.7%)	23.0 ± 0.2 (87.5%)	43	31	53	11	20
NH_4^+	(mg/L)	31.7 ± 5.1 (87.9%)	16.2 (84.8%)	20.1 ± 0.2 (95.2%)	40	27	---	---	12
TP	(mg/L)	3.5 ± 0.4 (75.3%)	1.9 (74.1%)	2.1 ± 0.3 (70.4 %)	9.7	7.2	7	2.2	4

Note: Percentage of dissolved concentration is provided in parenthesis

Sewer discharge concentration patterns in dry days are presented in **Figure 4-16**. The discharge concentrations did not show strong fluctuation among hours in a day and among days in a week, especially particulate concentrations. Even in the night time and early morning, when little of water was consumed, pollutant concentrations were slightly lower than those in daytime. According to a typical variation in domestic wastewater strength, BOD variation generally follows the discharge flow trend (Tchobanoglous *et al.*, 2004), which had two peaks in the daytime and decreased in the night time. V-Notch again might cause the impact on the hourly concentration pattern. The water stored inside sewer pipes caused by V-Notch might mix with the water which has just discharged and affect its quality.

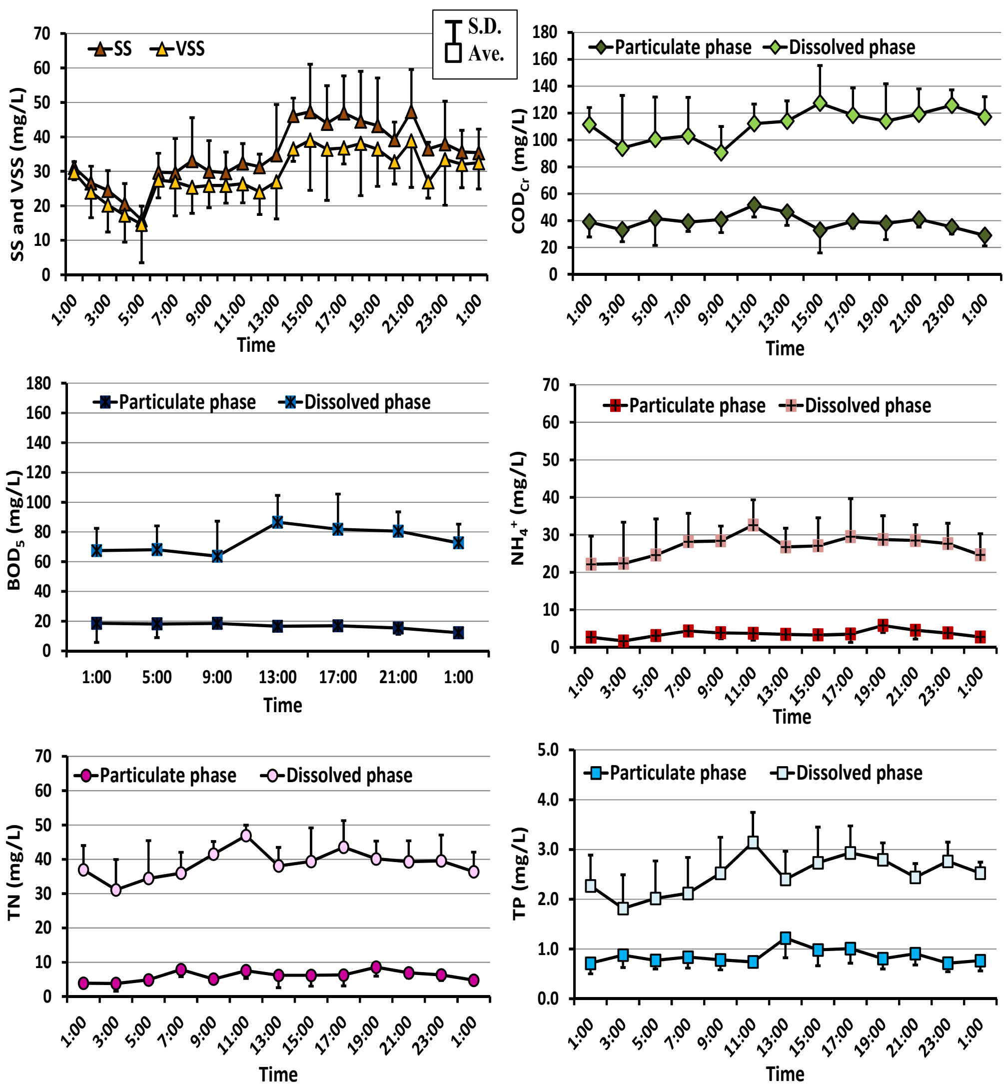

Figure 4-16 Discharge quality at sewer outlet in 24 hours on four dry days in dry season 2015

Discharge quality in wet weather condition

Pollutant concentrations in four rain events in rainy season 2015 were illustrated in **Figure 4-17**.

At the beginning of rain event, pollutants concentrations increased with the increase of rainfall and flow rate. The concentrations of pollutants reached at the peaks at rainfall intensities around 7.5 mm/h. At peaks, pollutants concentrations were many times higher than those on dry days in rainy season. This trend was observed most clearly during the rain event on 27 Nov. when the rain occurred in a long time with high intensity. On this day, SS concentration at the peak time was 2 times higher than that on dry days. Other parameters (COD_{Cr}, BOD_5, TN, TP, and NH_4^+) also increased higher than the average concentrations on dry days. This was observed as the first flush phenomenon. At the beginning of a rain event, high flow rate caused by strong rainfall intensity flushed out the accumulated pollutants inside the sewer system. In addition, run-off flows also contributed a great amount of pollutants into the sewer system at this time. These high additional amounts of pollutants not only could compensate for the concentrations decreased due to dilution effect but also increased the pollutants concentrations. However, after reaching the peak of discharge, pollutants concentrations decreased although rainfall and flow rate kept increasing. This can be explained by the dilution caused by large flow in the rain event. Because of the dilution effect, pollutant concentrations decreased many times (3 – 10 times) lower than those on dry days. This low trend of concentration in wet weather condition was also investigated in a wastewater influent at Georgia's wastewater treatment plants (Mines *et al.*, 2007) and Hanoi's wastewater treatment plant (Nga *et al.*, 2014).

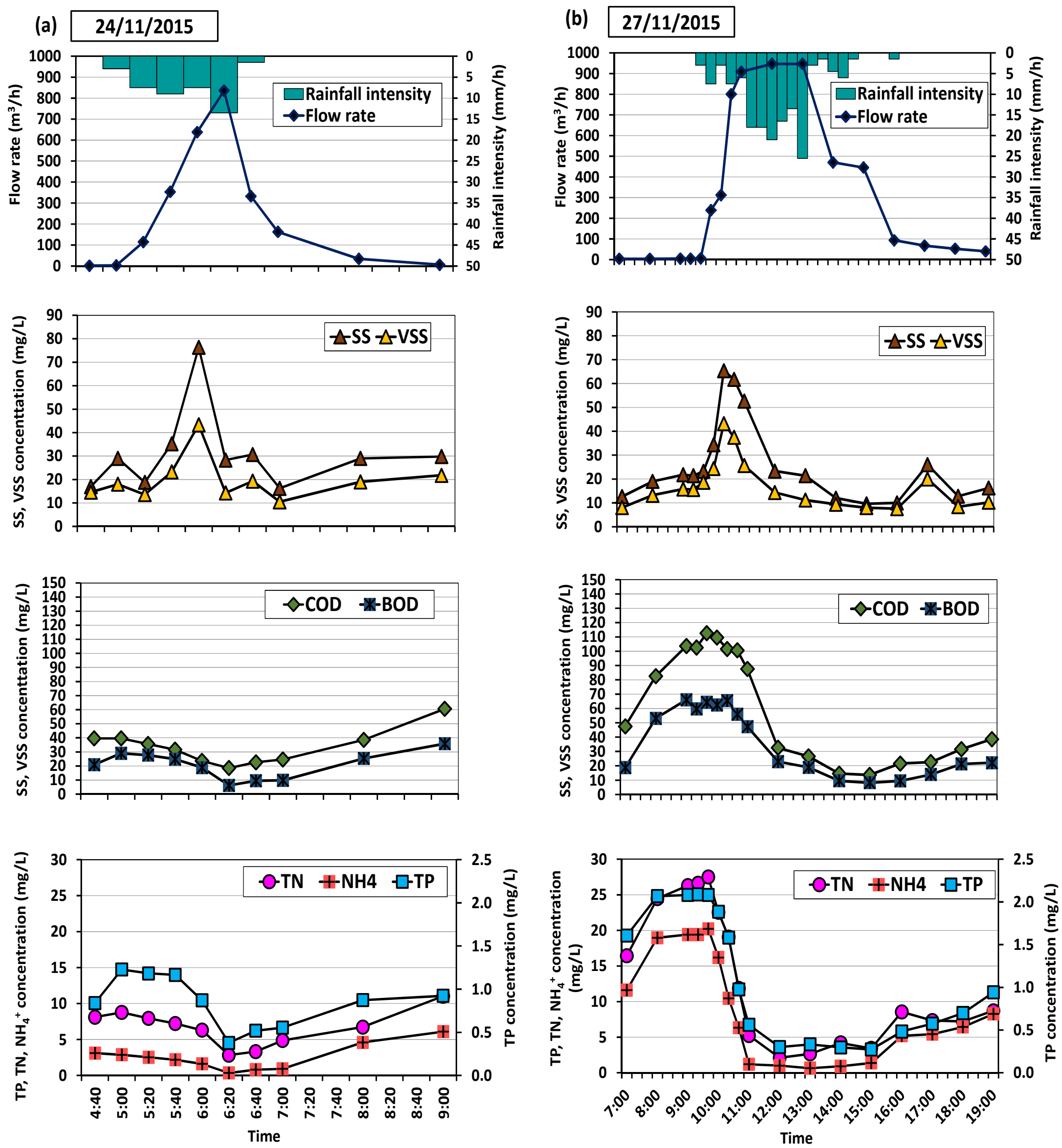

Figure 4-17 Variation of sewer discharge quality in rain events in rainy season 2015

4.3.5 Pollution loads from sewer to water body

Pollution loads on dry days

Pollution loads at the outlet on dry days in dry season showed the same pattern for all parameters in both dissolved and particulate phase (**Figure 4-18**). These patterns much resembled the patterns of discharge flow rate. There were two peaks of discharge loads (7:00 – 17:00 and 17:00 – 1:00). And the lowest loads were observed during the early morning time (1:00 – 7:00). A large amount of pollution loads came from dissolved matter (**Figure 4-18**) showed the dominant of dissolve matter in sewage constituent.

However, the particulate loads in reality might be higher since discharge particulate matter was affected by V-Notch as mentioned before.

Unit pollution loads of all parameters were showed in **Table 4-5**. Pollution loads on dry days in dry season were rather similar to those on dry days in rainy season and many times lower than those in other areas such as Iran (Mesdaghinia *et al.*, 2015), Japan (Tchobanoglous *et al.*, 2004), *etc.*. 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, particle settling due to low velocity of sewage in study area. Therefore, it is suggested that in-sewer processes, especially sewer leakage and settling process should be examined in a further study.

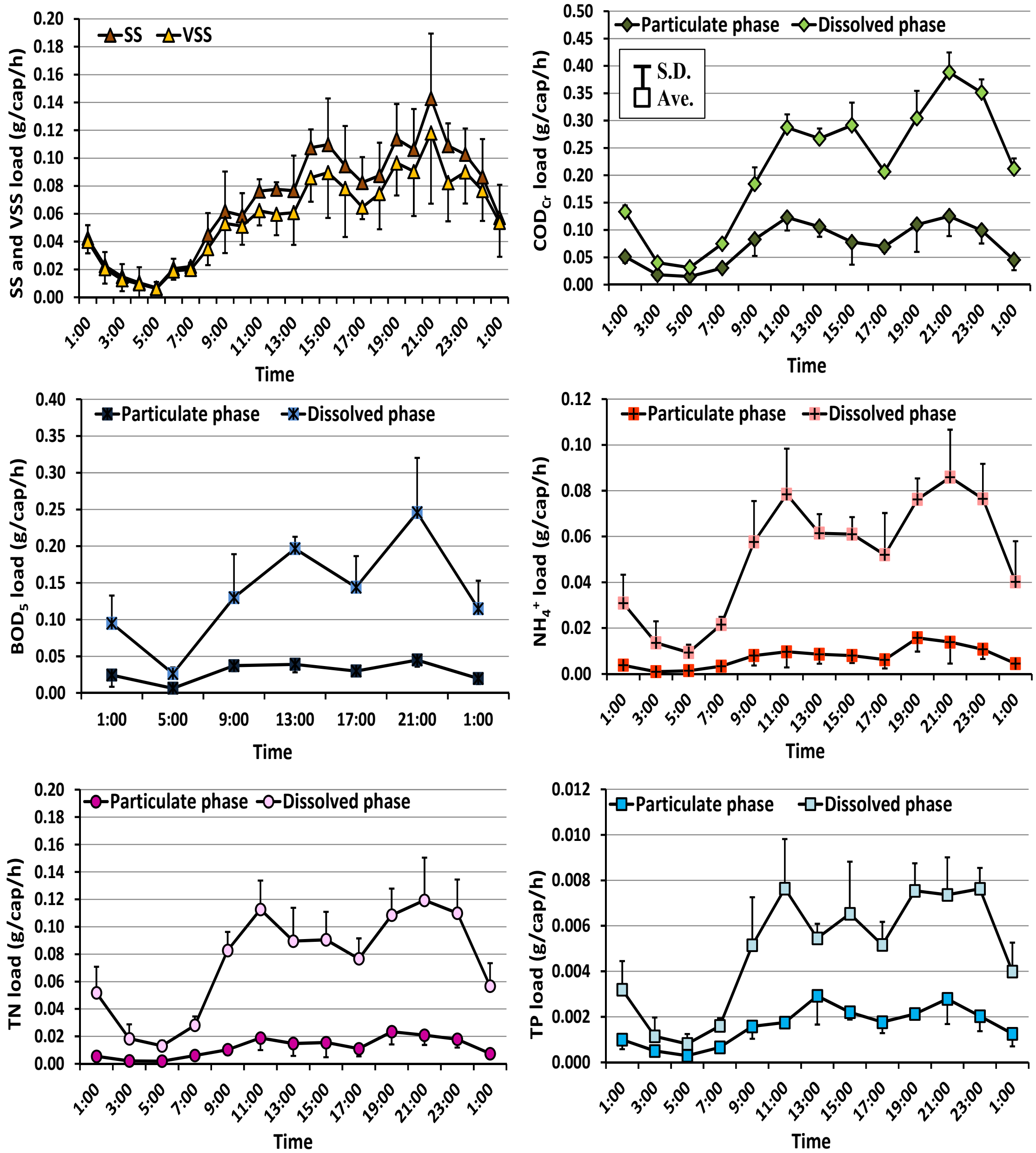

Figure 4-18 Average pollution loads at the sewer outlet on four dry days in dry season 2015

Table 4-5 Unit pollution loads from combined sewer system compared to those in other areas

Item		At sewer outlet			At HHs	At WWTPs (influent)	
		Hue - Dry season 2015	Hue - Rainy season 2015	Hue - Rainy season 2014	Hanoi [15]	Tehran, Iran [16]	Japan [3]
SS	(g/cap/day)	1.69±0.14	2.34	2.47±0.17	11.6 ± 5.1	37.31 ± 2.44	---
VSS	(g/cap/day)	1.40±0.17	2.07	1.73±0.74	---	---	---
COD_{Cr}	(g/cap/day)	6.99±0.61 (74.4%)	8.18 (78.2%)	7.36±2.24 (64.6%)	65.6 ± 10.4	49.25 ± 2.49	---
BOD_5	(g/cap/day)	4.11±0.42 (82.5%)	3.62 (79.6%)	2.71±1.12 (59.9%)	31.9 ± 5.3	32.96 ± 1.91	40-45
TN	(g/cap/day)	2.11±0.26 (85.8%)	1.81 (77.9%)	2.40±0.58 (86.2%)	7.6 ± 0.9	6.77 ± 0.53	1-3 (*)
NH_4^+	(g/cap/day)	1.44±0.05 (87.5%)	1.38 (84.1%)	2.09±0.48 (95.5%)	---	---	---
TP	(g/cap/day)	0.16±0.00 (75.0%)	0.16 (75.0%)	0.22±0.02 (68.3%)	1.1 ± 0.1	1.96 ± 0.11	0.15-0.4

Note: (1) Percentage of dissolved concentration is provided in parenthesis
(2) (*) is TKN

Pollution loads in wet weather condition

On rainy days, pollution loads fluctuated together with rainfall intensity and discharge flow rate. The fluctuation of pollution loads are shown in **Figure 4-19** for rain events on 24 Nov. 2015 and 27 Nov. 2015 as representatives. Similar to concentration trend, pollution loads reached at the peak at rainfall intensities around 7.5 mm/h. After that, pollution loads decreased although rainfall intensity and flow rate kept increasing, as shown in **Figure 4-19**. Pollution loads at these discharge peaks were higher than average discharge loads on dry days in rainy season from about 15 times to nearly 400 times. Different with dry days in dry season, where dissolved loads dominated the total loads, in rain events, particulate matter accounted for a large amount of the total loads at peaks (**Figure 4-20**).

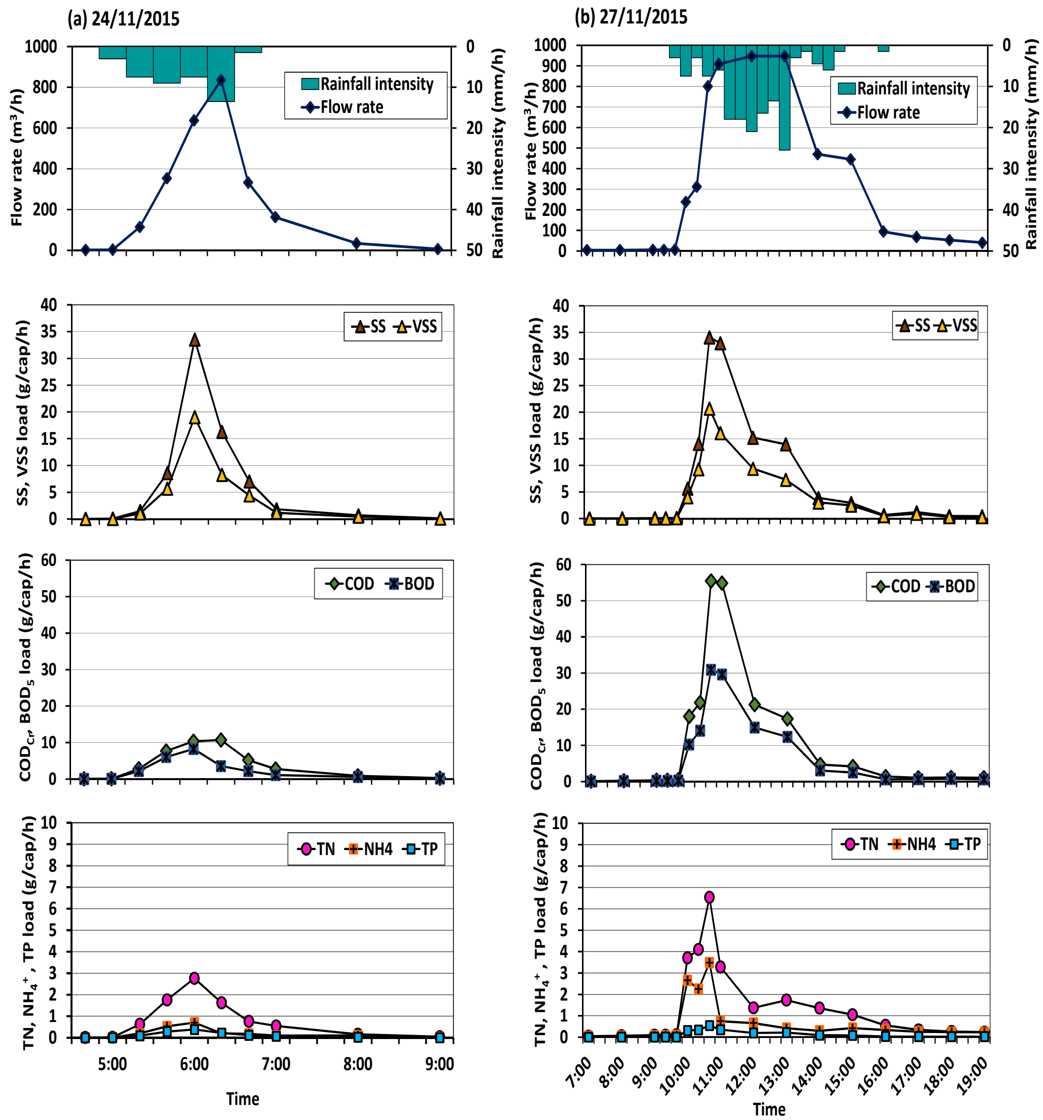

Figure 4-19 Pollution loads during rain events on 24 Nov. 2015 (a) and 27 Nov. 2015 (b)

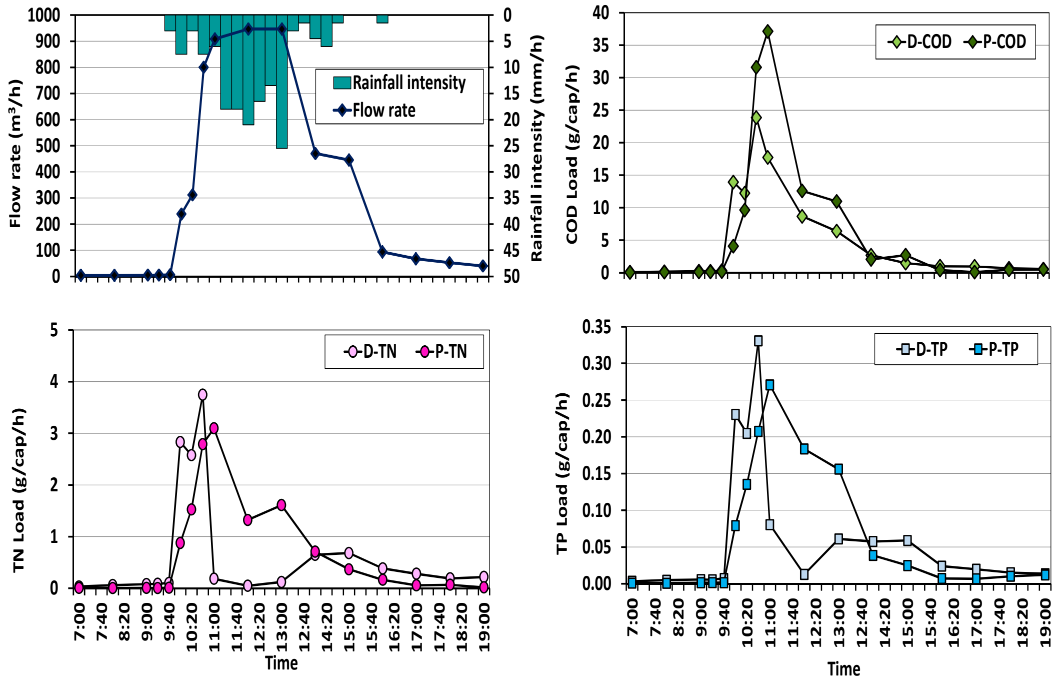

Figure 4-20 Particulate and dissolved loads during rain event on 27 Nov. 2015

Relationships between pollution loads and discharge flow rates were described as *L*-*Q* equations (**Figure 4-21)**. Flow rates affected different parameters at different levels, which were presented by *n* values in equations. All the pollutant loads increased with the increase of flow rates. Among parameters, SS and VSS had the highest value of *n* (*n*=1.05 and 1.02 for SS and VSS, respectively), which showed that SS and VSS loads tended to increase more greatly with the increase of flow rates than the others. This can be explained as follows, SS and VSS might accumulate in sewers more than other pollutants and they were also discharged more quickly at high intensities of rain. Follow SS and VSS, COD_{Cr} and BOD_5 had higher values of *n* than TN and TP, which showed that organic matter loads tended to increase more greatly with the increase of flow rates than nutrients. NH_4^+ had the lowest *n* value, which indicated the slow increase in discharge load when the flow increased. This is probably NH_4^+ was mainly found in dissolved phase and very little of NH_4^+ in particulate phase was accumulated in sewer system or came from runoff flows. More details about the deposition of each pollutant and its discharge should be considered in a further study, and the *L*-*Q* equation should be improved so that it includes more exact effects of the phenomenon of accumulation and discharge in the sewer. Calculating accumulated loading in sewer before a rain event and integrating it into the *L*-*Q* equation are possibly important works for future researches.

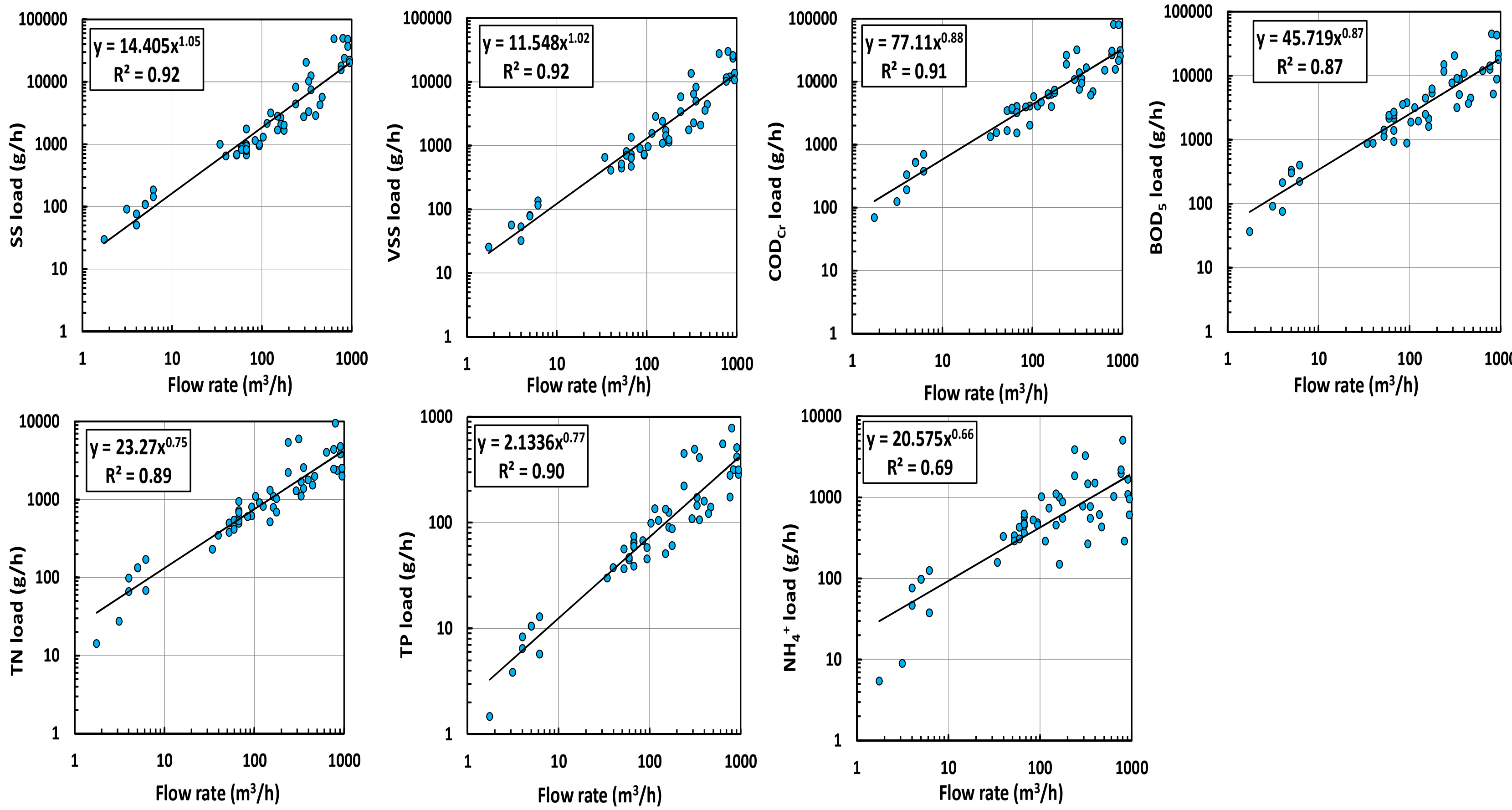

Figure 4-21 Relationship between pollution loads and discharge flow rates in wet weather condition

4.4 Conclusions

This chapter presented the characteristics of discharge from a combined sewer system at a small residential drainage area in Hue city. The variation of discharge flow rate and discharge quality was investigated in short term (hourly variation) and long term (seasonal variation). On dry days in dry season, the hourly variation of discharge flow rate basically corresponded to a water consumption trend. Two peaks of discharge were observed from 6:00 - 17:00 and from 17:00 - 0:00, and the lowest discharges were observed during the early morning (1:00 - 6:00). On dry days in rainy season, discharge flow rate variably changed among hours in a day without any rules of pattern. The average discharge flow rate on dry days in dry season was 2.72±0.32 m^3/h (44.9±5.4 L/cap/day), which was about half of that on dry days in rainy season (4.99±0.55 m^3/h (82.5±9.1 L/cap/day) in 2015, and 5.38±2.15 m^3/h (88.9±35.5 L/cap/day) in 2014). In this survey, discharge flow rate was not different among dry days or between weekdays and weekends. On rainy days in rainy season, discharge flow rate fluctuated with rainfall intensity, stronger rainfall intensities corresponded to a higher discharge flow rates. Under the effect of rain, discharge flow rate during rainy time increased many time higher than dry weather discharge flow. It seems that only rain events with intensities higher than 1mm/h were observed to cause impact on discharge flow rate. However, more observation should be conducted to confirm the level of rainfall intensities that can impact discharge flow rates.

The sewage quality on dry days in both dry and rainy season was characterized by low concentrations of pollutants, which demonstrated that domestic wastewater in urban Hue was not strongly polluted in terms of organic matters and nutrients. The low concentration of SS and the small proportion of particulate phase in sewer discharge in this study supports our argument that in-sewer settling significantly contributed to the low strength discharge in this study. The discharge concentrations fluctuated slightly during 24 hours in a day and among days in a week. V-Notch was probably one of the reasons of this slight fluctuation as well as the low particulate concentration since it could slow down the velocity and create the condition for water stored and matter settling down inside the sewer pipes. It is suggested that wastewater samples should be collected at the forward position placement of V-Notch so that the impact of V-Notch on discharge quality could be prevented. On rainy days, total concentrations of all parameters increased with the increase of rainfall intensities and flow rate at the beginning time of rain and reached the highest concentrations at the rainfall intensities around 7.5 mm/h. This phenomenon was observed as the first flush phenomenon. The higher particulate concentration than dissolved concentration observed during high rainfall intensity times might reinforce this argument that in-sewer accumulated matter and pollutants from run-off flows were the main sources of pollutants in the first flush. After reaching the peaks of discharge, pollutants concentrations decreased even when rainfall intensities and flow rates kept increasing, which was due to the dilution caused by large flows

Flow rates showed the strong influence on pollutant loads. Pollution loads at the outlet on dry days and rain events were rather resembled the patterns of discharge flow rate. *L*-*Q* equations showed that showed that SS and VSS loads tended to increase more greatly with the increase of flow rates, followed by COD_{Cr} and BOD_5, TN and TP and NH_4^+. Dissolved matter mainly contributed to the total loads on dry days while particulate matter showed the important contribution at high rainfall intensities time. A remarkable difference among unit pollution loads from sewer systems in study area on dry days and other countries suggested that in-sewer processes, especially sewage leakage and settling process should be studied more detail.

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Publications

Reviewed paper

1. Tran Nguyen Quynh Anh, Hidenori Harada, Shigeo Fujii , Pham Nguyet Anh, Pham Khac Lieu, and Shuhei Tanaka (2015). Characterization of combined sewer discharge in Hue city, Vietnam. *Journal of Science and Technology*, **53**(3A), 187-192.
2. Tran Nguyen Quynh Anh, Hidenori Harada, Shigeo Fujii , Pham Khac Lieu, Duong Van Hieu, and Shuhei Tanaka (2016). Sewer discharge characteristics and water balance in dry season in Hue, Vietnam. *Journal of Science and Technology*, **54**(2A), 265-272.

Presentation

1. Tran Nguyen Quynh Anh, Hidenori Harada, Shigeo Fujii , Pham Nguyet Anh, Pham Khac Lieu, and Shuhei Tanaka (2015). Characterization of combined sewer discharge in Hue city, Vietnam. *International Forum on Green Technology and Management,* July 28th - 30th, Hue city, Vietnam.

Chapter 5 Continuous monitoring of sewer flow rate and establishing of water balance in a combined sewer system in Hue, Vietnam

5.1 Introduction

Water consumption and wastewater generation in a locality vary throughout the day, during the week and throughout the year (Von Sperling, 2007). These variations are influenced by many factors such as the climate, socio-economic factors, household facilities, *etc.* The variations are important for design, operation and control of wastewater treatment facilities. However, in developing countries, these variations were not monitored well since it is very costly to measure the real quantity of wastewater flow throughout a day or a year. Planning and designing often use standardized quantity data, resulting in improper performance of wastewater treatment plants. Our previous surveys (**Chapter 4**) have supplied some information on the variation of discharge flow rate. However, due to the limitation of the number of survey days, given results might not reflect the representative characteristic of discharge flow rate. Because good characterization of wastewater is a critical matter for the optimization of wastewater treatment process, in this chapter, we continue to characterize sewer discharge quantity in Hue city to obtain its representative discharge flow rate by a continuous monitoring of discharge flow rate in one month in dry season 2016.

Moreover, the balance of water in sewer system is a key point to understand the system behavior (Hlavinek *et al.*, 2006) as well as to understand the impact of the system on surrounding environment. The sewer systems in most urban areas in developing countries were built in a long time ago. Over the years, many of these systems have experienced major infrastructures deterioration due to inadequate preventive maintenance programs and insufficient planned system rehabilitation and replacement programs. These conditions have resulted in deteriorated pipes, manholes, *etc.* that allows sewage to exit the systems (exfiltration) or water from outside sources to enter the system (infiltration). These uncontrolled flows of water have caused many adverse impacts on the sewerage system itself (Bosseler *et al.*, 2014). Besides, water balance of sewer system can affect the local water balance or groundwater balance. In some cases, high levels of infiltration can lower groundwater levels and can cause significant hydrologic impacts to nearby streams.

There have been some studies in developed countries which developed water balances for sewer system. Whereas, in developing countries, where the sewerage systems are seriously damaged due to poor design and construction, this kind of information has not been paid attention to yet. Therefore, the second objective of this chapter is to construct a water balance of the sewer system. From that, the impacts of wastewater from the system to the surrounding environment could be predicted which will help for a good management strategy.

5.2 Materials and methods

5.2.1 Study site

The study area is a residential drainage area in Thuan Thanh ward, Hue Citadel, Hue city, Vietnam, as described in previous chapter (**Chapter 4**).

5.2.2 Continuous discharge flow rate survey

A flow sensor (2150 AV - ISCO) (**Figure 5-1**) and a 90^o V-Notch weir were used in combination to measure flow rate in the situation of very low velocity of sewage (**Figure 5-2**). The V-Notch was installed inside the sewer pipe and the sensor which was attached on the middle bottom of a stainless scissors mounting ring was fixed at 1 meter upstream side in the pipe from the V-Notch. The recorder (**Figure 5-1**) was fixed inside the man hole. A computer running Flowlink software was connected with the recorder to set up the measurement mode and retrieve the data.

The flow sensor can automatically read the water depth (*h*) (from the bottom of the sewer pipe to the water surface) (**Figure 5-2**). By using the recorded water level data, the head of the weir (*H*) was inferred, and then sewer flow rate could be calculated using the Cone equation as mentioned in the previous chapter. The measurement mode was set up at 15 minutes interval during 29 days in March 2016. Before using the system, the sensor was set up at 15 seconds measurement mode and kept for one week to check its operation. The accuracy of sensor was also checked by comparing the value of water level recorded by sensor with value measured by ruler and value observed on V-Notch.

Together with flow rate recording, rainfall amount was also measured by an automatic rain gauge. Rainfall amount was set up to record at 10 minutes interval.

Figure 5-1 A flow sensor 2150 AV – ISCO connects with recorder

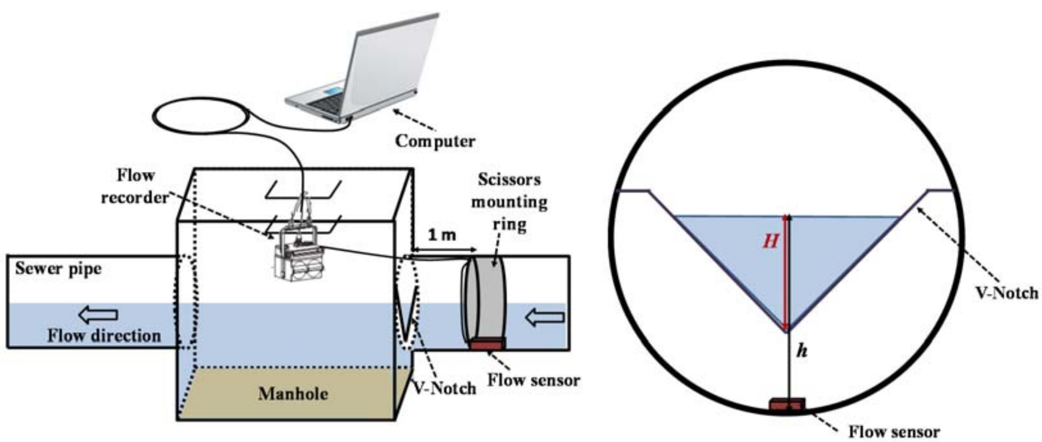


Figure 5-2 Experimental set up to continuously measure flow rate

5.2.3 Water balance calculation

A water balance was calculated for the sewer system on dry days and rainy days in dry season and rainy season in year 2014, 2015, and 2016 (**Figure 5-3**).

Water inflows included:

(1) Household greywater amount discharged into the sewer system (*HG*) (m^3/day);
(2) Household septic tank effluent amount discharged into the sewer system (*ST*) (m^3/day);

(3) Water amount from runoff come into the sewer system when rain occur (*RO*) (m^3/day);

(4) Water infiltration from underground into the sewer system (*IF*) (m^3/day).

Water inflows included:

(1) Sewage amount discharged at the final outlet of the sewer system (*Q*) (m^3/day);

(2) Water exfiltration from the sewer system to underground (*EF*) (m^3/day).

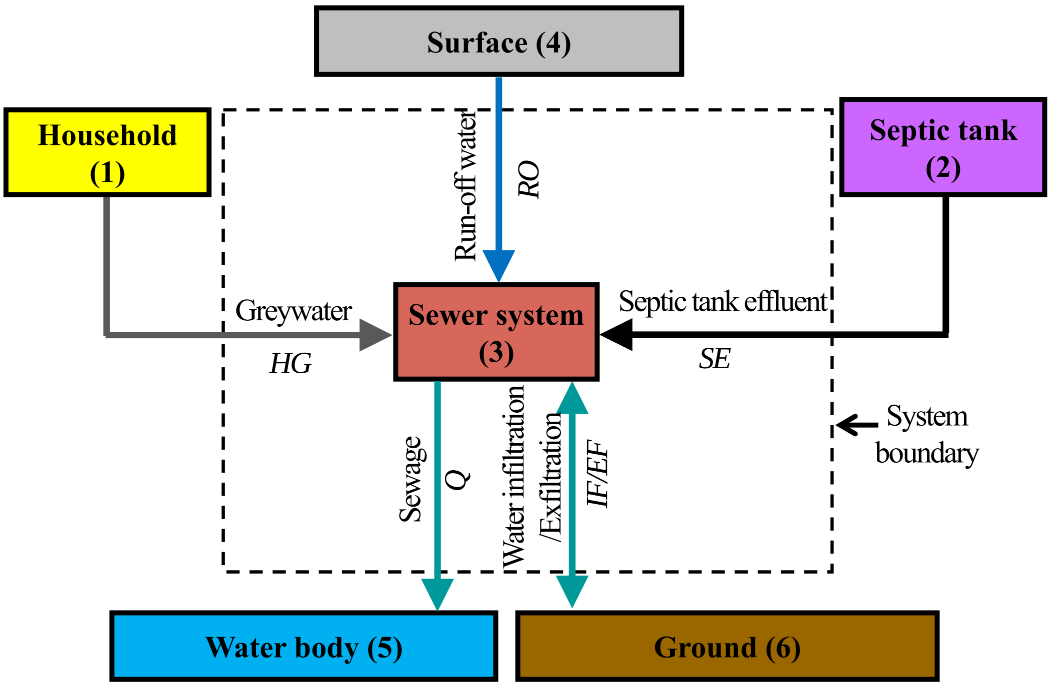


Figure 5-3 Water balance in sewer system

Then, hydrological equation for sewer system was written as:

$$HG + SE + RO \pm IF/EF = Q \quad \textbf{(Eq. 5-1)}$$

HH greywater (HG) and HH septic tank effluent (SE) discharge

Amount of greywater and septic tank effluent from households discharged into sewer system were calculated as follows:

$$HG = Q_{HG} \times r_{HG} \quad \textbf{(Eq. 5-2)}$$

$$SE = Q_{ST} \times r_{ST} \quad \textbf{(Eq. 5-3)}$$

Where Q_{HG}: amount of greywater generated from households (m^3/day);

Q_{SE}: amount of septic tank effluent generated from households (m^3/day);

r_{HG}: ratio of household discharged their greywater into sewer system;

r_{SE}: ratio of household discharged their septic tank effluent into sewer system.

Q_{HG} and Q_{SE} were estimated as 80% and 20% of total water consumption amount (Anh, 2014), respectively. Total water consumption amount in drainage area was 153.7 L/cap/day in 2015, and 134.0 L/cap/day in 2014 (HUEWACO, 2013 & 2015).

Values of r_{HG} *and* r_{SE} (0.94 and 0.53, respectively) were obtained from our survey on wastewater management for 100 households in the drainage area - which was detailed mentioned in the previous chapter (**Chapter 4**).

Water runoff (RO)

Water runoff happens normally on rainy days when there are heavy rains or the underground is saturated of water. Water runoff amount come into sewer system was estimated by rational equation (Davis and Cornwell, 2013):

$$RO = c \times i \times A/1000 \quad \textbf{(Eq. 5-4)}$$

Where RO: water runoff amount (m^3/event)

c: runoff coefficient. Value of c was chosen as 0.65 for a residential area with small garden;

i: rainfall intensity (mm/event). Rainfall intensity data was obtained from rainfall survey as described in **Section 5.2.2**;

A: drainage area (m^2) (A = 112,000 m^2);

1000: conversion factor from mm to m.

Sewage discharge (Q)

Sewage amount discharged at the final outlet of the sewer system was obtained from our four surveys of flow rate discharge as described in the previous sections (**Chapter 4-Section 4.2.4,** and **Chapter 5-Section 5.2.2**).

Water infiltration or exfiltration (IF/EF)

Up to now, it's still not easy to determine the water amount come into or go out from infiltration or exfiltration phenomenon in the sewer system. There was two ways to estimate the amount of water infiltrated/exfiltrated to/from sewer: directly measurement and indirectly estimation based on water balance. In this study, water infiltration to or exfiltration from the sewer system was estimated by mass conservation law:

$$IF/EF = HG + SE + RO - Q \qquad \textbf{(Eq. 5-5)}$$

There was water from somewhere infiltrated into the sewer system if ($HG + SE + RO - Q$) value was negative. In contract, there was water exfiltration from sewer system to underground.

5.3 Results and discussions

5.3.1 Fluctuation of discharge flow rate at the sewer outlet on dry days in dry season

Our continuous survey of discharge flow rate was conducted on 29 days in March 2016. There were 26 dry days and 3 rainy days (rainfall amount from 2.5 mm/day – 4.5 mm/day (**Figure 5-4**)).

Discharge flow rate strongly fluctuated among dry days in a month but did not follow any patterns (**Figure 5-4**). Daily discharge flow rates among dry days showed a significant difference (P<0.05) (ANOVA table is shown in **Appendix II (B)**), which reflected total water consumption amount was different among days. Average discharge flow rate on dry days in March was 2.27±0.44 m^3/h (equivalent to 54.6±10.5 m^3/day or 37.5±7.3 L/cap/day). The highest flow rate reached 3.10 m^3/h (on 19 March) and the lowest flow rate was 1.39 m^3/h (31 March). Compared to average discharge flow rate on dry days in dry season in 2015 (2.72±0.32 m^3/h), average rate in March 2016 was slightly lower.

There was a significant difference in the discharge between weekdays and weekends (P<0.05) (ANOVA table is shown in **Appendix II (B)**). The discharge rate on weekends (2.47±0.38 m^3/h) was higher than that on weekdays (2.21±0.45 m^3/h). This might be explained by higher water consumption on weekends. On weekends, many people stay at home and do house cleaning, which consume much water than usual. The result was different from that of our previous surveys in which the difference between weekdays and weekends was not investigated (**Chapter 4**). This might because of the limitation amount of survey days in the previous survey.

On dry season, rain events with small rainfall intensity (under 4.5 mm/day) seemed not affect discharge flow rate. On 11, 27 and 28 March, flow rates were not increased although there were small rains.

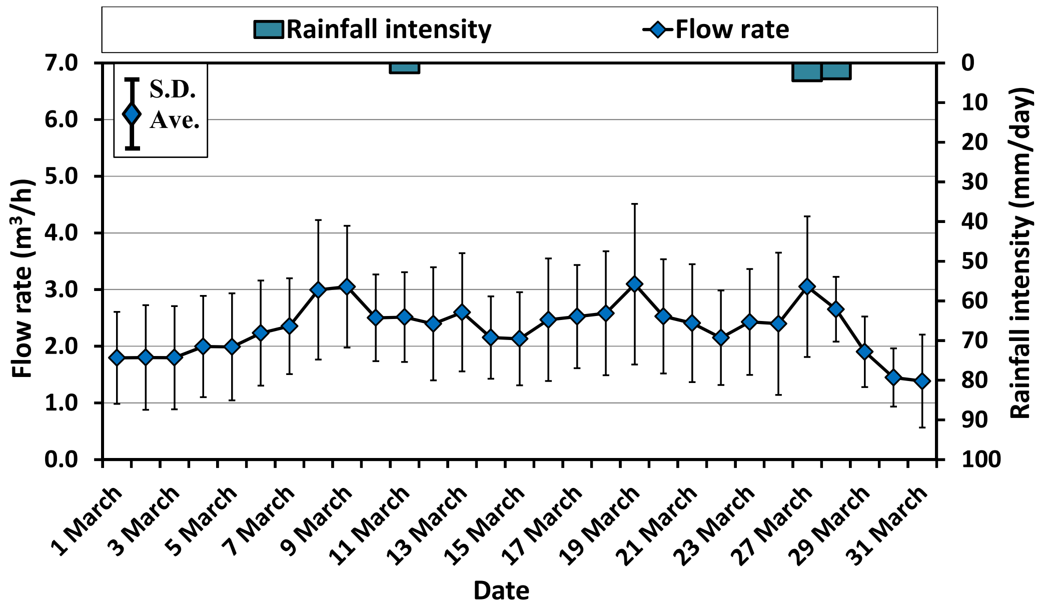


Figure 5-4 Daily variation of discharge flow rate in March 2016

Although the average amounts of discharge flow rate were different among days in a month, discharge patterns of these days were rather similar (**Figure 5-5**). Two peaks of discharge were observed from 6:00 – 16:00 and from 16:00 – 24:00, corresponding to the water consumption trend. Lowest discharge was observed during the early morning (from 1:00 – 6:00), corresponding to very little of water consumption due to people went to sleep. This pattern was similar to the pattern observed from previous surveys.

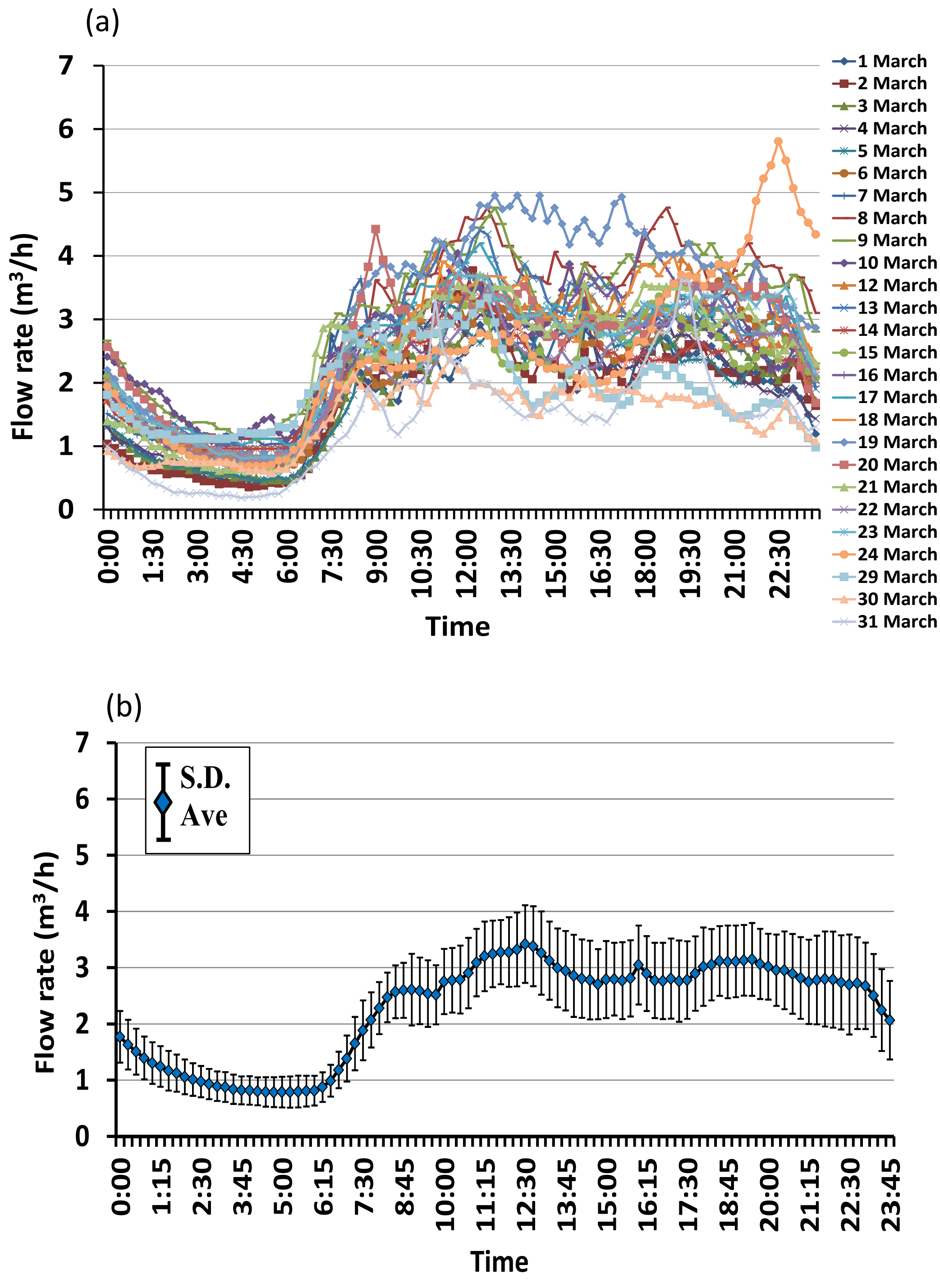


Figure 5-5 Hourly variation of discharge flow rate in March 2016 in all days (a) and in average dry days (*n*=26) (b)

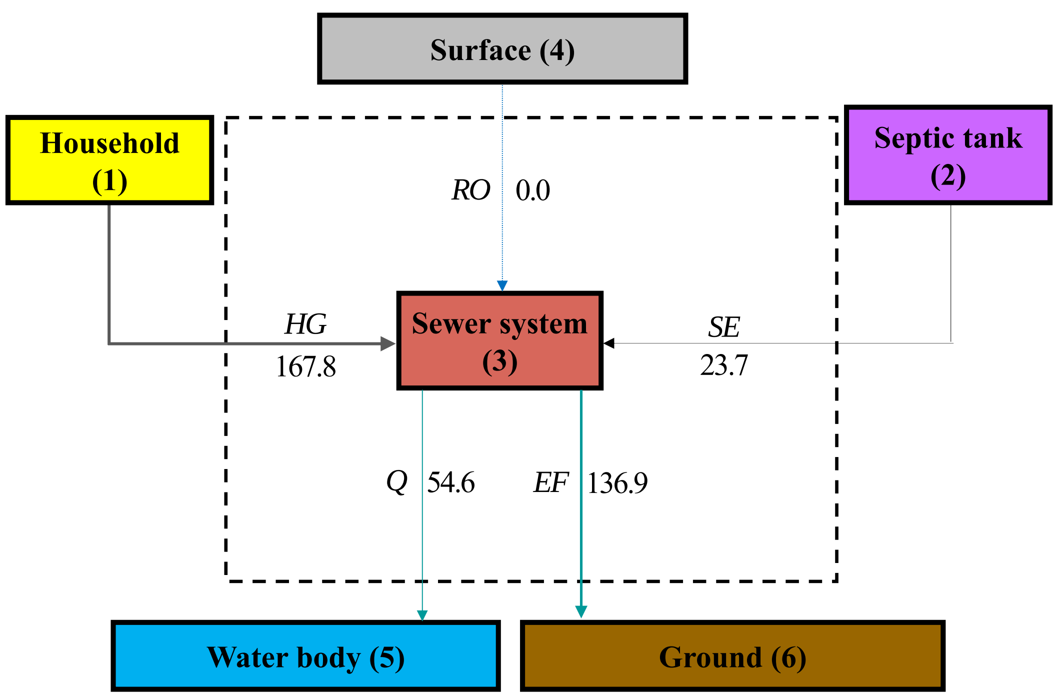
5.3.2 Water balance in a combined sewer system in Hue

Water balance of the combined sewer system was similar for dry days in both dry season and rainy season and different with rainy days patterns. Therefore, water balance is shown for average dry days in dry season 2016, dry days in rainy season 2015, and for two rainy days with different rainfall intensities in rainy season 2015 as representatives (**Figure 5-6)**. Besides, water infiltration and exfiltration from the sewer system at different weather conditions are shown in **Figure 5-7**.

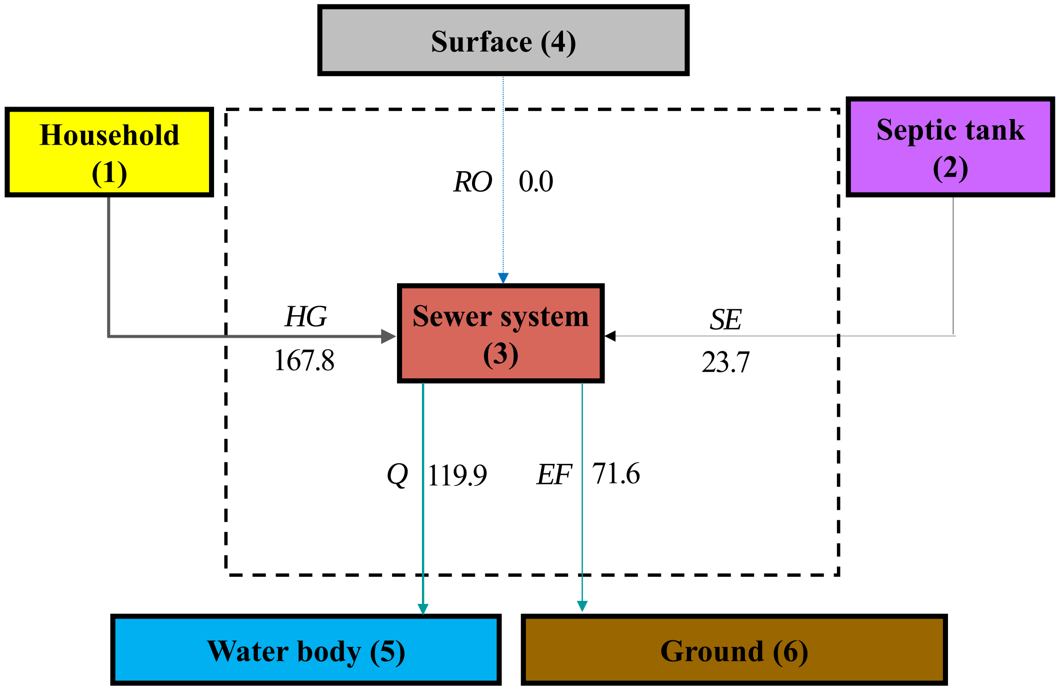
On dry days, water entered the sewer system were mainly grey water and septic tank effluent, and water outputted from the system were sewage discharged into water bodies and water exfiltrated into the ground through leakage from the sewer system. Although water balances showed the same pattern for dry days in both dry season and rainy season, the ratio of sewage discharged at the outlet and the ratio of sewage exfiltrated into the ground between these seasons were very different. On dry days in dry season, sewage discharge amount to water bodies was rather small compared to exfiltrated amount (**Figure 5-6 (a)**). Meanwhile, on dry days in rainy season, sewage reached the outlet was slightly higher than the exfiltrated amount (**Figure 5-6 (b)**). For example, on dry days in dry season 2016, sewage reached the outlet only accounted for 17.4% - 38.8% of total water input (28.5% in average). The same trend was also observed on dry days in dry season 2015 with 34.0% sewage reached the outlet to discharge to the water body. Meanwhile, on dry days in rainy season 2015, sewage reached the outlet (62.6% of water input) was higher than the exfiltrated amount (37.4% of water input). The difference in sewage discharge flow rate between dry season and rainy season might be due to the saturation condition of soil in these seasons. On dry season, the soil might be very dry and it absorbed much sewage leaked from sewer system. In contrast, on rainy season, the soil contained much water from previous rain events and could not absorb much more water compared to dry season. The leakage ratio of wastewater from sewer system varied very much among areas (accounted for 1% - 56% of total dry weather flow) (Rutsch *et al.*, 2008) and was governed by many factors such as pipe material, age of sewer, *etc.* (Bishop *et al.*, 1998). The high leakage ratio in our study area might be due to the sewer system in Hue city was rather old, incomplete and poorly maintained. Some part of the sewer system was soil ditch, which made a large amount of water permeated into soil before reach the sewer pipes. Besides, the sewer system was not maintained annually due to the limitation of budget (HEPCO, 2013). This situation should be paid attention since it might potentially pollute soil or ground water in the area. However, since the leakage wastewater amount in this study was estimated indirectly by a water balance, a further study focus on sewer leakage should be conducted in the future in this area.

Water balances on rainy days in rainy season were different to those on dry days. On rainy days, run-off from surface contributed a large amount of water to the sewer system (48.7% to 95.2% of total water input). Under the impact of rainfall, the amount of water discharged at the sewer outlet increased greatly, which accounted for 81.3% of total water inputted on a 14mm rain event on 24 Nov. 2015 and even higher than the total water inputted on a 52.5 mm rain event on 27 Nov. 2015. However, the water balance pattern seemed different at different rainfall intensities. On a light rain (14 mm/event), there was water exfiltrated from the sewer system (18.7% of total water inputted). Meanwhile, on a heavy rain (52.5 mm/event), the water from the ground likely infiltrated to the sewer system. However, since the amount of water discharged at the sewer outlet on rainy days was not so accurately estimation, the water balance pattern on rainy days needs to be rechecked in the future to understand more exactly.

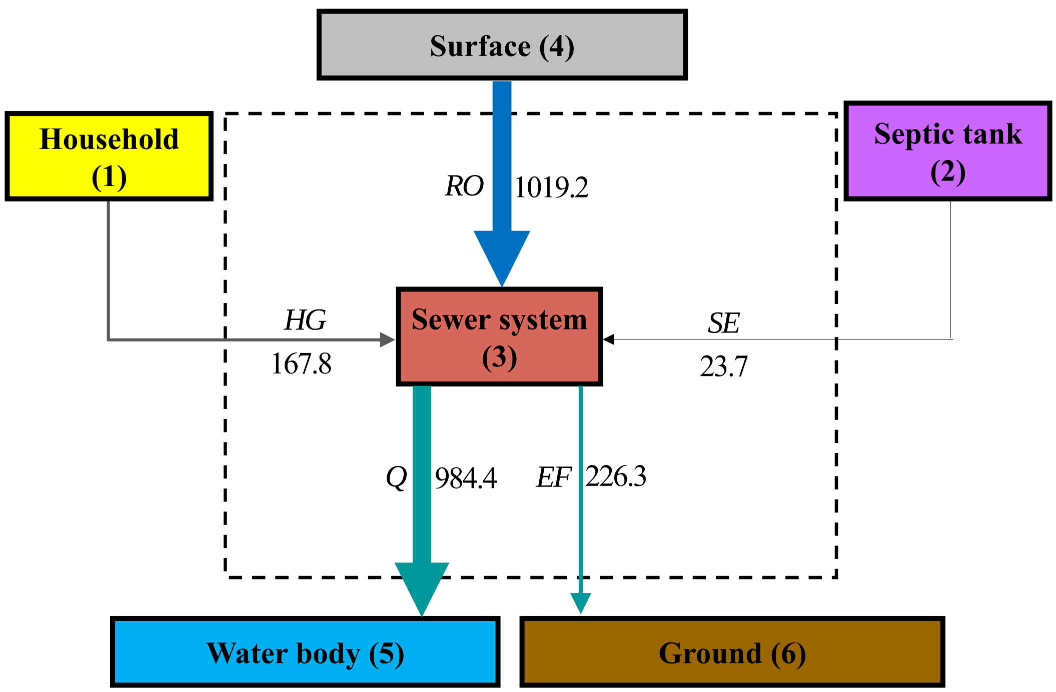
(a) Average dry days in dry season 2016 (March) (*n*=26) (m^3/day)



(b) Average dry days in rainy season 2015 (November) (*n*=4) (m^3/day)



(c) A light rainy days (14 mm/day) in rainy season 2015 (24 November) (m^3/day)



(d) A heavy rainy days (52.5 mm/day) in rainy season 2015 (27 November) (m^3/day)

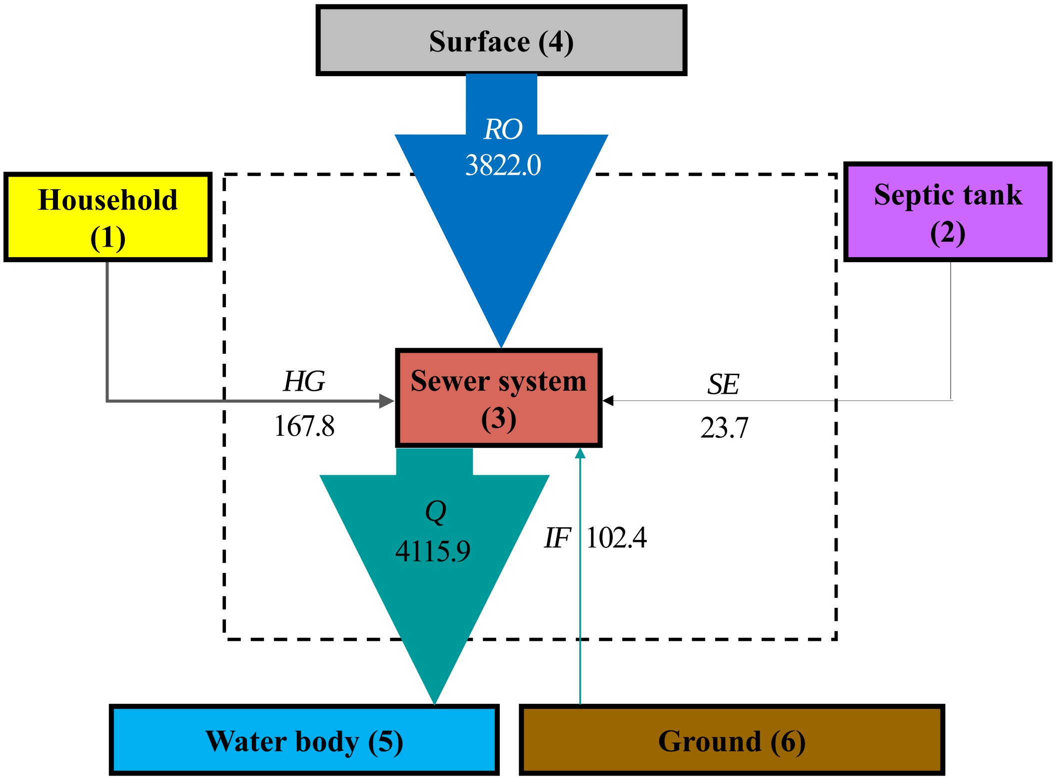


Figure 5-6 Water balance in sewer system in different weather conditions (m^3/day)

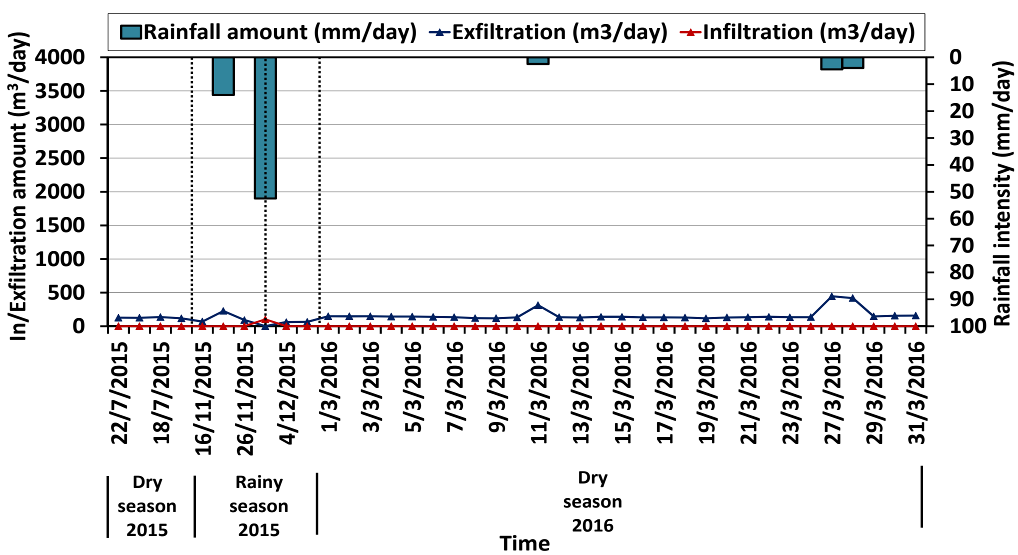


Figure 5-7 Water exfiltration from sewer system (m^3/day)

5.4 Conclusions

This chapter presented results from a one-month continuous monitoring of discharge flow rate in dry season 2016. Discharge flow rate fluctuated strongly among days in a month without any regulation. Average discharge rates were different among day and between weekdays and weekends ($P<0.05$). Average discharge flow rate on dry days in dry season 2016 was 2.27±0.44 m^3/h (equivalent to 54.6±10.5 m^3/day or 37.5±7.3 L/cap/day), which was slightly lower than that on dry days in dry season 2015 (2.72±0.32 m^3/h). Hourly discharge flow rates during 24 hours of all dry days had the same pattern with two peaks of discharge rate (from 6:00 - 16:00 and from 16:00 - 24:00). The lowest discharge rates were in the early morning time (from 1:00 - 6:00). This reflected that water consumption amount by people living in the area might vary among days but water consumption behavior and timing were similar for every day. Water balances of the sewer system were similar for all dry days in both dry season and rainy season in which water exfiltrated from the sewer system into the ground. Meanwhile, water balance on rainy days in rainy season showed different patterns at different rainfall intensities. On a light rainy day (14 mm/event), there was water exfiltrated from sewer to the ground. In contrast, water likely came into the sewer system from the ground on a heavy rainy day (52.5 mm/event). One important matter which should be noticed was that discharge flow rate at the sewer outlet on dry days in dry season only accounted for 28.5% (in 2016) – 34.0% (in 2015) of the total water inputted the system. It meant that up to 66.0% - 71.5% of wastewater did not reach at the outlet, and potentially exfiltrated into ground through leakage from sewer pipes. This was an alarm situation since this huge amount of sewage could contaminate soil and groundwater. However, since the exfiltrated water amount was estimated indirectly by water balance, it is suggested that exfiltration phenomenon should be studied more details in further studies.

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Chapter 6 Material flow analysis in a residential drainage area in Hue, Vietnam

6.1 Introduction

Currently, the development of many urban areas in developing countries has led to changes in lifestyles, infrastructures, and the characteristics of waste and wastewater management. For example, in Vietnam, access to an improved water source and toilet has increased from 90% and 64% in 1990 to 98% and 93% in 2012, respectively (WHO & UNICEF, 2014), likely resulting in material flow changes. A study in a suburban community in Hanoi, Vietnam showed that the shift from traditional agricultural practices of reusing waste to the application of chemical fertilizers had led to an increase of phosphorus input to paddy fields, an increase of 1.3 times from 1980 to 2010, which exceeded the recommended level by 3.5 times (Giang *et al.*, 2015). Thus, it is crucial to study waste and wastewater management and the effects on material flow to improve urban environments in developing areas.

Presently, material flow analysis (MFA) has demonstrated as a valuable tool in resource management and waste management in many countries since it connects sources, the pathways, the intermediate and final sinks of a material (Brunner P. H. and Rechberger H., 2004). The phosphorus flow through the municipality of Gävle, Sweden was quantified, and results showed that two-thirds of phosphorus accumulated mainly at waste dumps while the remaining third left the system as outflows to the Baltic Sea or to the market as a product (Nilsson, 1995). A study on phosphorus balance in Sydney, Australia revealed that 80% of phosphorus inputs to the system were derived from foods and detergent; 90% of outputs from the system were discharged to the ocean as effluent from wastewater treatment plants (Tangsubkul *et al.*, 2005). In China, the phosphorus flows in two cities (Hefei and Chaohu) located near Chaohu Lake were studied; excessive chemical fertilizers from farming operations and sewage discharge from household activities were identified as the most critical sources of phosphorus loading into surface water (Li *et al.*, 2010; Yuan *et al.*, 2011). In Vietnam, phosphorus flows have been quantified for several areas in the northern part of the country, *e.g.*, Hanoi city and Hanam province, which mainly focused on the interaction between environmental sanitation and agricultural systems (Giang *et al.*, 2015; Montangero *et al.*, 2007; Nga *et al.*, 2011); they revealed that the harmonization between these systems can increase nutrient recovery and reduce the nutrient loading to the environment.

In most urban areas in developing countries, the amount of domestic wastewater has increased over times. Due to the lack of wastewater treatment facilities, a great amount of domestic wastewater along with many pollutants contained in wastewater was discharged into the environment. The flow of domestic wastewater discharge potentially impacted the material flow through urban areas. To manage effectively material flows in urban areas, the impacts of domestic wastewater discharge on the material flows need to be well understood. The objectives of this chapter were to describe the nutrients flows (P and N) in a residential drainage area in Hue, Vietnam and quantify the impact on domestic sewer discharge on the nutrients flows. By that, appropriate solutions could be suggested in order to well manage the nutrients flows to protect the environment.

6.2 Materials and methods

6.2.1 Study site

The study area is a residential drainage area in Thuan Thanh ward, Hue Citadel, Hue city, Vietnam, as described in **Chapter 4** of thesis.

6.2.2 Data collection

Development of material flow model needs a lot of data. Necessary data were collected by different methods: sewer survey (**Chapter 4** and **5**), structured interview (**Chapter 4**), and secondary data collection.

Data investigated in this study. Data obtained from our sewer survey and structured interview in the two previous chapters were showed in **Table 6-1**.

Table 6-1 Data obtained from our survey in this study

Contents	Unit	Value	Reference	Symbol
Ratio of greywater that went to sewer system	-	0.94	Structured interview	$R_{3(gw)}$
Ratio of greywater that went to surface ground	-	0.05	Structured interview	$R_{6(gw)}$
Ratio of greywater that went to a water body	-	0.01	Structured interview	$R_{5(gw)}$
Ratio of OSS effluent that went to sewer system	-	0.53	Structured interview	$R_{3(tw)}$
Ratio of OSS effluent that went to underground	-	0.46	Structured interview	$R_{6(tw)}$
Ratio of OSS effluent that went to a water body	-	0.01	Structured interview	$R_{5(tw)}$
Ratio of HHs with desludging experience	-	0.35	Structured interview	h_{de}
Average desludging interval years	year	10	Structured interview	f_{fs}
Run-off water amount	m^3/event		Rainfall survey	RO
- On 27 Nov. 2015		3822.0		
- On 24 Nov. 2015		1019.2		
Unit P rate in sewer discharge	g/cap/day		Sewer survey	$U_{3P(sg)}$
- On dry days in dry season		0.16		
- On dry days in rainy season		0.16		
Unit N rate in sewer discharge	g/cap/day		Sewer survey	$U_{3N(sg)}$
- On dry days in dry season		2.11		
- On dry days in rainy season		1.81		
Sewer discharge amount	m^3/day		Sewer survey	Q
- On 27 Nov. 2015		4115.9		
- On 24 Nov. 2015		984.4		

Secondary data collection. **Table 6-2** summarizes the secondary data collected for this study. Demographic, socioeconomic, and meteorological information on the Citadel was obtained from official city reports. Phosphorus concentration data of wastes, wastewater, and other environmental media were obtained from references to calculate a phosphorus flow.

Table 6-2 Secondary data

Contents	Unit	Value	Source	Symbol
Population in 2015	people	1452	1)	P
Total drainage area	ha	11.2	2)	S
Unit phosphorus rate by human excreta	g/(cap·day)	1.2	3)	$U_{1P(he)}$
Unit nitrogen rate by human excreta	g/(cap·day)	8.1	3)	$U_{1N(he)}$
Phosphorus transfer coefficient in fecal sludge from septic tank	-	0.18	3)	$U_{2P(fs)}$
Nitrogen transfer coefficient in fecal sludge from septic tank	-	0.09	3)	$U_{2N(fs)}$
Unit phosphorus rate by HH greywater	g/(cap·day)	0.6	4)	$U_{1P(gw)}$
Unit nitrogen rate by HH greywater	g/(cap·day)	1.0	4)	$U_{1N(gw)}$
Unit phosphorus rate by kitchen wastes	g/(cap·day)	0.16	5)	$U_{1P(kw)}$
Unit nitrogen rate by kitchen wastes	g/(cap·day)	0.65	5)	$U_{1N(kw)}$
Ratio of HH kitchen wastes went to landfill	-	0.82	6)	$R_{7(kw)}$
Ratio of HH kitchen wastes reused for pig breeding	-	0.18	6)	$R_{9(kw)}$

1) People's Committee of Thuan Thanh ward (2016); 2) CIT (2013b); 3) Montangero and Belevi (2007); 4) Busser (2007); 5) Schouw *et al.* (2002); 6) Anh *et al.* (2016).

6.2.3 Nutrient flows development

A material flow model was developed to quantify the phosphorus and nitrogen flow (P/N) in a residential drainage area in urban Hue, Vietnam (**Figure 6-2**). The system boundary is defined as the boundary of the target drainage area. The model has three components inside the system boundary, *i.e.* household (j=1), on-site sanitation system (j=2), and a sewer system (j=3), and six components outside the system boundary, *i.e.* surface (j=4), water body (Tinh Tam Lake) (j=5), ground and storage (j=6), landfill (j=7), atmosphere (j=8), and market (j=9).

Each individual P/N flow was calculated using the unit value method. The P/N flow of a material k from component i to component j, $P_{i,j(k)}$, was calculated as follows:

$$P_{i,j(k)} = \left(U_{i(k)} \times C_{(k)} \times R_{j(k)}\right)/S \qquad \textbf{(Eq. 6-1)}$$

Where $U_{i(k)}$: unit phosphorus or nitrogen discharge (transfer) rate of material k from component i (g/(unit amount · day));

$C_{(k)}$: discharge amount of material k (unit amount);

$R_{j(k)}$: ratio transferred to component j (dimensionless);

S: total area of the study site (ha).

The flows, which could not be calculated by unit value method, were calculated based on mass conservation law, which is as follows:

$$Total\ input\ to\ component\ m \left(\sum_{k}\sum_{i} P_{i,m(k)}\right) = Total\ output\ from\ component\ m \left(\sum_{k'}\sum_{j} P_{m,j(k')}\right) \qquad \textbf{(Eq. 6-2)}$$

Details of each equation are shown in **Table 6-3**.

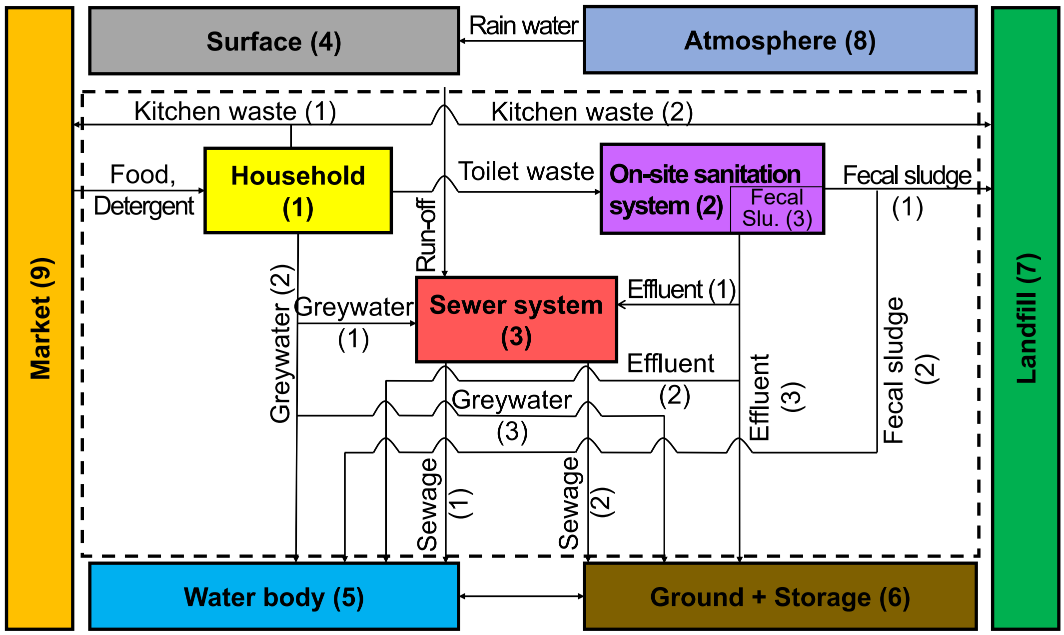

Figure 6-1 A material flow model

Table 6-3 Equations for the calculation of individual phosphorus or nitrogen flows (g/(ha · day))

Component (*j*) from-to	Material	Equation	
Household to on-site sanitation system	Toilet waste (*tw*)	$P_{1,2(tw)} = \left(U_{1(he)} \times P\right)/S$	(Eq. 6-3)
Household to sewer system	Greywater (*gw*)	$P_{1,3(gw)} = \left(U_{1(gw)} \times P \times R_{3(gw)}\right)/S$	(Eq. 6-4)
Household to water body	Greywater (*gw*)	$P_{1,5(gw)} = \left(U_{1(gw)} \times P \times R_{5(gw)}\right)/S$	(Eq. 6-5)
Household to ground/groundwater	Greywater (*gw*)	$P_{1,6(gw)} = \left(U_{1(gw)} \times P \times R_{6(gw)}\right)/S$	(Eq. 6-6)
Household to landfill	Kitchen waste (*kw*)	$P_{1,7(kw)} = \left(U_{1(kw)} \times P \times R_{7(kw)}\right)/S$	(Eq. 6-7)
Households to market	Kitchen waste (*kw*)	$P_{1,9(kw)} = \left(U_{1(kw)} \times P \times R_{9(kw)}\right)/S$	(Eq. 6-8)
Market to household	Food, detergent (*fd*)	$P_{9,1(fd)} = P_{1,2} + P_{1,3} + P_{1,5} + P_{1,6} + P_{1,7} + P_{1,9}$	(Eq. 6-9)
On-site sanitation system to sewer system	Effluent (*ef*)	$P_{2,3(ef)} = \left[P_{1,2} - \left(P_{1,2} \times \mathrm{U}_{2(fs)}\right)\right] \times R_{3(tw)}$	(Eq. 6-10)
On-site sanitation system to water body	Effluent (*ef*)	$P_{2,5(ef)} = \left[P_{1,2} - \left(P_{1,2} \times \mathrm{U}_{2(fs)}\right)\right] \times R_{5(tw)}$	(Eq. 6-11)
On-site sanitation system to ground/groundwater	Effluent (*ef*)	$P_{2,6(ef)} = \left[P_{1,2} - \left(P_{1,2} \times \mathrm{U}_{2(fs)}\right)\right] \times R_{6(tw)}$	(Eq. 6-12)

On-site sanitation system to landfill	Fecal sludge (*fs*)	$P_{2,7(fs)} = \left[\left(P_{1,2} \times \mathrm{U}_{2(fs)} \times h_{de}\right)/f_{fs}\right]/S$	(Eq. 6-13)
On-site sanitation system storage	Fecal sludge (*fs*)	$P_{2,2(fs)} = \left(P_{1,2} \times U_{2(fs)}\right) - P_{2,7}$	(Eq. 6-14)
Surface to sewer system	Run-off (*ro*) - P: - N:	$P_{P4,3(ro)} = (0.0086\ \times RO^{-0.44})\ \times RO$ $P_{N4,3(ro)} = (0.1979\ \times RO^{-0.69}) \times RO$	(Eq. 6-15) (Eq. 6-16)
Sewer system to water body - Dry days: - Rainy days:	Sewage (*sg*) - P: - N: - P: - N:	$P_{P3,5(sg)} = \left(U_{3P(sg)} \times P\right)/S$ $P_{N3,5(sg)} = \left(U_{3N(sg)} \times P\right)/S$ $P_{P3,5(sg)} = (2.13\ \times Q^{0.77})/S$ $P_{N3,5(sg)} = (23.27\ \times Q^{0.75})/S$	(Eq. 6-17) (Eq. 6-18) (Eq. 6-19) (Eq. 6-20)
Sewer system to ground and storage	Sewage (*sg*)	$P_{3,6(sg)} = P_{1,3} + P_{2,3} + P_{4,3} - P_{3,5}$	(Eq. 6-21)

6.3 Results and discussions

6.3.1 Nutrient flows in a residential drainage area

The estimated phosphorus (P) and nitrogen (N) flows in the target drainage area on average dry days in dry season (DdDs) in 2016 (*n*=26 dry days in March) are shown in **Figure 6-2**.

Households discharged a large amount of P and N (254.1 g P/(ha·day) and 1264.0 g N/(ha·day)), which was derived from toilet waste (155.6 g P/(ha·day) and 1051.1 g N/(ha·day)), greywater (77.8 g P/(ha·day) and 129.6 g N/(ha·day)), and kitchen waste (20.7 g P/(ha·day) and 84.3 g N/(ha·day)). Therefore, the control of pollution load from households is an important consideration.

As evident in **Figure 6-2**, on-site sanitation systems (septic tanks and cesspools) received the greatest amount of P and N from households (62.1% and 83.1%, respectively). The P and N loading of effluent from the sanitation systems was 127.6 g P/(ha·day) and 955.6 g N/(ha·day), respectively, of which 53.0% went into the sewer system, 46.0% was discharged the ground/groundwater, and only 1.0% was discharged to the water body. The great amount of P and N from on-site sanitation effluent was a potential source of pollution that affected soil and groundwater quality of the area. The

P and N loading of fecal sludge was 28.0 g P/(ha·day) and 94.5 g N/(ha·day). The amount of P and N in fecal sludge collected and dumped at a city landfill were too small since the number of on-site sanitation systems have been desludged was rather small (35.0% of the total OSS) and the average desludging interval was too long (10 years). This situation led to most of P and N in fecal sludge still remained in the facilities of on-site sanitation systems. The great amount of fecal stored in on-site sanitation systems might reduce the ability of septic tanks in pre-treatment of toilet waste and led to the increase of P and N in the discharge effluent to sewer and the environment. If the stored sludge is well managed such as be removed regularly and legally disposed or treated, it can help in reducing the P and N discharge to the environment. Therefore, the improvement of on-site sanitation systems might help to better control the nutrient flows.

The sewer system received a similar amount of P in greywater from households (73.1 g P/(ha·day) – 52.0% of total P input to sewer system) and in effluent from on-site sanitation systems (67.6 g P/(ha·day) – 48.0% of total P input to sewer system). Meanwhile, N came to sewer system was mainly from on-site sanitation effluent (506.5 g N/(ha·day) – 80.6% of total N input to sewer system). Greywater from households only accounted for 19.4% of total N came to sewer system. The sewer system was supposed to play an important role in conveying wastewater together with pollutants from generation sources to the receiving water (here is Tinh Tam Lake). However, in this survey, only 14.7% of total P inputted the sewer system (20.7 g P/(ha·day)) traveled to the lake. The huge remaining of P inputted (85.3%) might store inside the sewer system as accumulated sludge or came into the ground through exfiltration. In case of N, 43.5% of N inputted the sewer system (273.5 g N/(ha·day)) reached the outlet to discharge into Tinh Tam Lake, 56.5% of inputted N was accumulated in sewer system or exfiltrated into the ground.

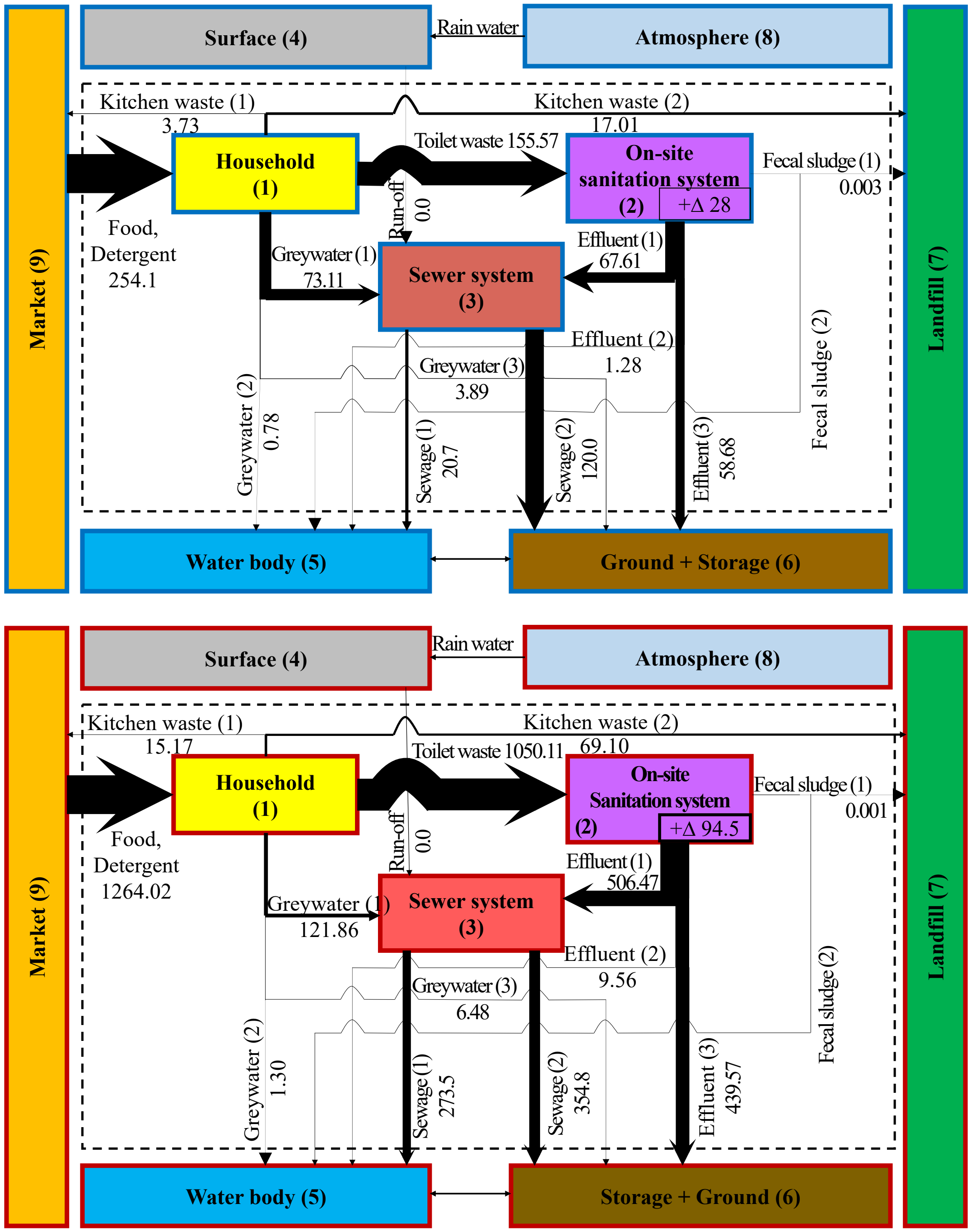

Figure 6-2 P flow (above) and N flow (below) on dry days in dry season 2016 (g/(ha·day))

6.3.2 Destination of nutrient flows and impact of sewer discharge on nutrient flows to the environment

The P and N flows were also developed in the target drainage area on dry days in rainy season 2015 (DdRs) (*n*=4 dry days), a heavy rainy day in rainy season 2015 (HdRs), and a light rainy day in rainy season 2015 (LdRs) (**Figure 6-3** - **Figure 6-5**) to assess the impact of sewer discharge on the nutrient flows at different weather conditions. The final destinations of P and N in the target drainage area are summarized in **Figure 6-6**. P and N mainly came to the water body or came to the ground or stored inside the sewer system/OSS. The amount of P and N went to landfill or markets were very small. Among components that discharged P and N to the water body, sewer system was the component contributed the greatest amount of P and N on both dry days and rainy days in dry season and rainy season. On dry days in dry season, P and N discharged from the sewer system accounted for 91.0% and 96.2% of total P and N came to the water body, respectively. The same situation was observed for dry days in rainy season (P: 91.0% and N: 95.6%). The contribution of sewer discharge to total P and N came to the water body was higher on rainy days (P: 91.0% and N: 95.6% on 27 Nov. 2015). It showed that the management of sewer discharge is very essential to manage the nutrient flows come to the water body. As Hue city plans to establish a centralized wastewater treatment plant, treatment of sewage from the sewer system will contribute to the reduction of P and N went to the environment.

One important matter that should be paid attention was that the amount of P and N discharged to the water body varied strongly at different weather conditions. On dry days in dry season, only 14.7% P (20.7 g P/(ha·day)) and 43.5% N (273.5 g N/(ha·day)) inputted the sewer system were discharged to the water body from the sewer outlet (**Table 6-2**). On dry days in rainy season, the situation was rather similar with 20.7 g P/(ha·day) and 234.73 g N/(ha·day) came to the water body (**Table 6-3**). It meant that a large remaining amount of P and N possibility accumulated inside the sewer system or exfiltrated into the ground. The low velocity of water inside sewer pipe on dry days might create the suitable condition for P and N settled down and thus reduced the P and N amount reach at the sewer outlet. If a great amount of P and N went to the ground, they will be a potential pollution source to contaminate soil and groundwater. On the contrary, if the major amount of P and N was accumulated as sewer sludge inside sewer pipes, they could be easily managed by sludge treatment and dredging. However, at this moment, the amount of P and N stored inside sewer pipes and P and N went to the ground were not known. Therefore, it is suggested that the P and N concentration in ground water should be investigated to understand the situation of groundwater quality in the study area. Moreover, the accumulation of P and N inside the sewer system should be further studied.

On rainy days in rainy season, the amount of P and N discharged to the water body increased greatly under the impact of rainfall. On these days, P and N came to the water body were many times higher than those on dry days. On 24 Nov. 2015 (rainfall intensity: 14 mm/day), P and N loads to the water body were 76.4 g P/ha/day and 795.6 g N/ha/day, which were higher than those on dry days in dry season 3.7 times and 2.9 times, respectively (**Figure 6-5**). On 27 Nov. 2015 (rainfall intensity: 52.5 mm/day), P and N loads to the water body increased up to 271.7 g P/(ha·day) and 2787.8 g N/(ha·day), 13.1 and 10.2 times higher than those on dry days in dry season for P and N (**Figure 6-4**). Especially, on a heavy rainy day (27 Nov.), P and N discharged to the water body were higher than the total P and N inputted to the sewer system. This meant that there were some other sources contributed to P and N budget in the sewer system on heavy rainy days. These sources might be from infiltration from ground or the flush out of accumulated sludge inside the sewer system under the high velocity of flow at high rainfall intensities. Therefore, if the accumulated sludge inside sewer on dry days was well managed, such as the sludge was removed from the sewer system before the rainy season, the amount of P and N loads to the water body could be reduced. Moreover, a better management and maintenance of sewer system which can prevent the water from ground infiltrated into the sewer system might also reduce the P and N loads to the surface water.

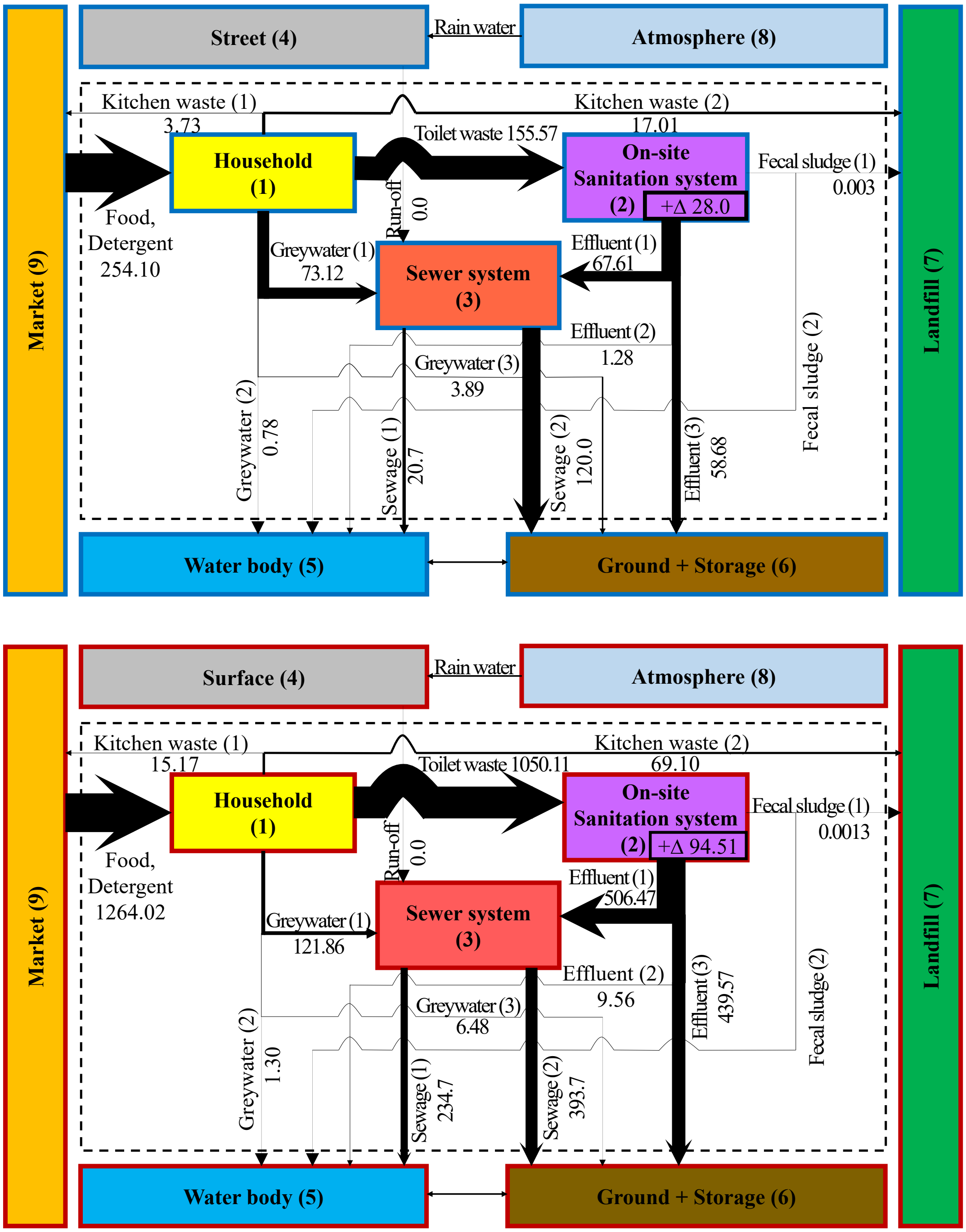

Figure 6-3 P flow (above) and N flow (below) on dry days in rainy season 2015 (g/(ha·day))

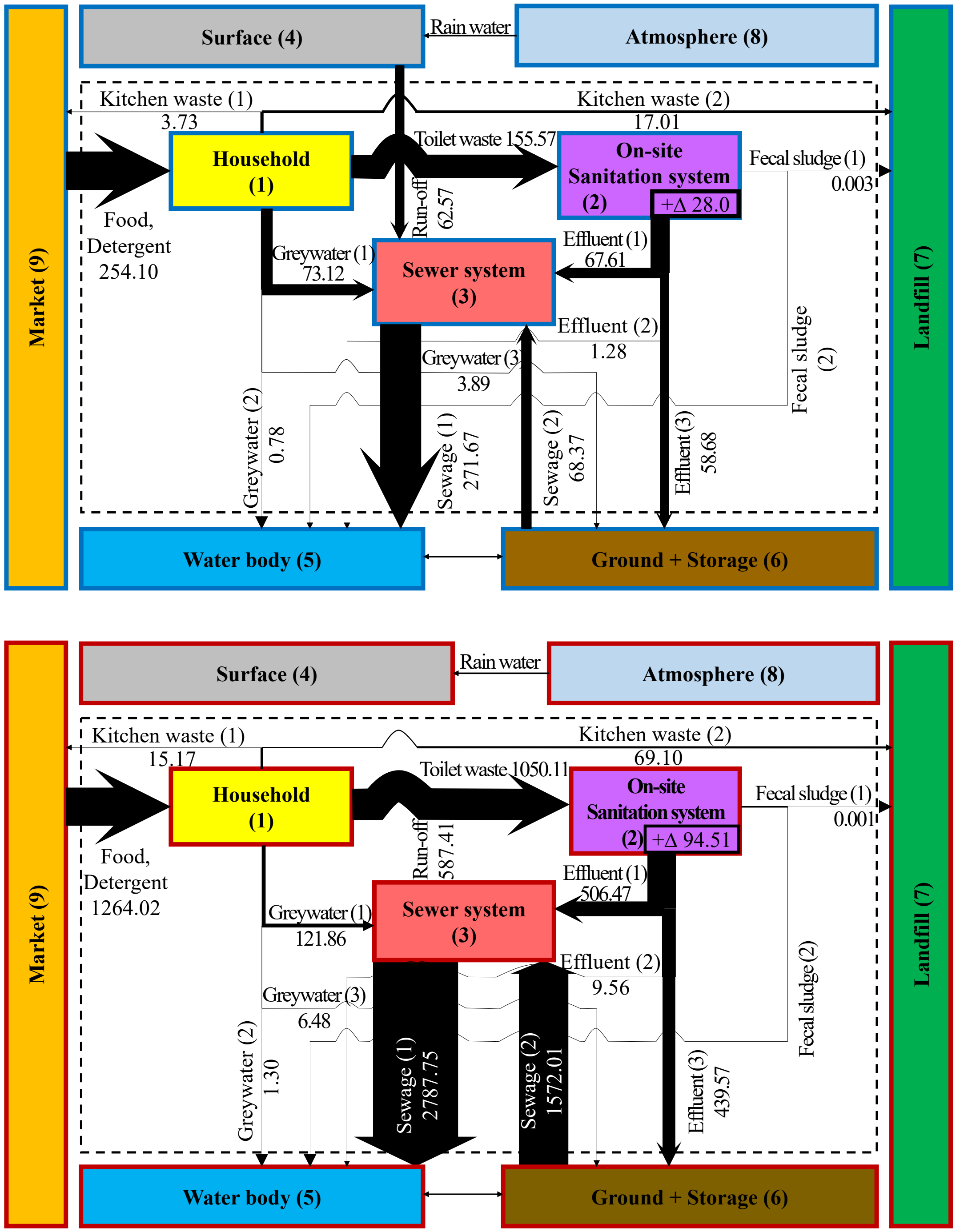

Figure 6-4 P flow (above) and N flow (below) on a heavy rainy day in rainy season 2015 (27 Nov., rainfall amount 52.5 mm/event) (g/(ha·day))

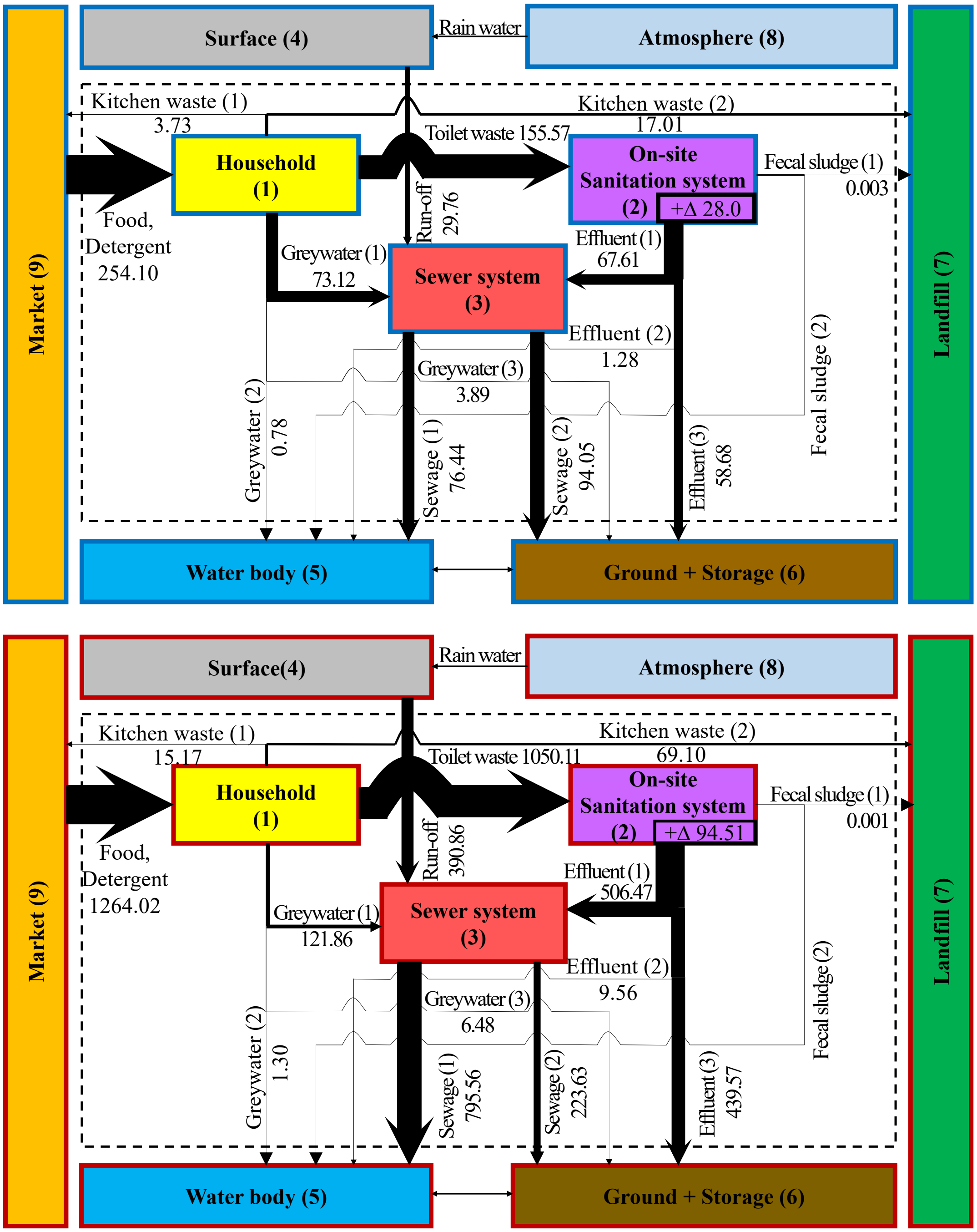

Figure 6-5 P flow (above) and N flow (below) on a light rainy day in rainy season 2015 (24 Nov., rainfall amount 14 mm/event) (g/(ha·day))

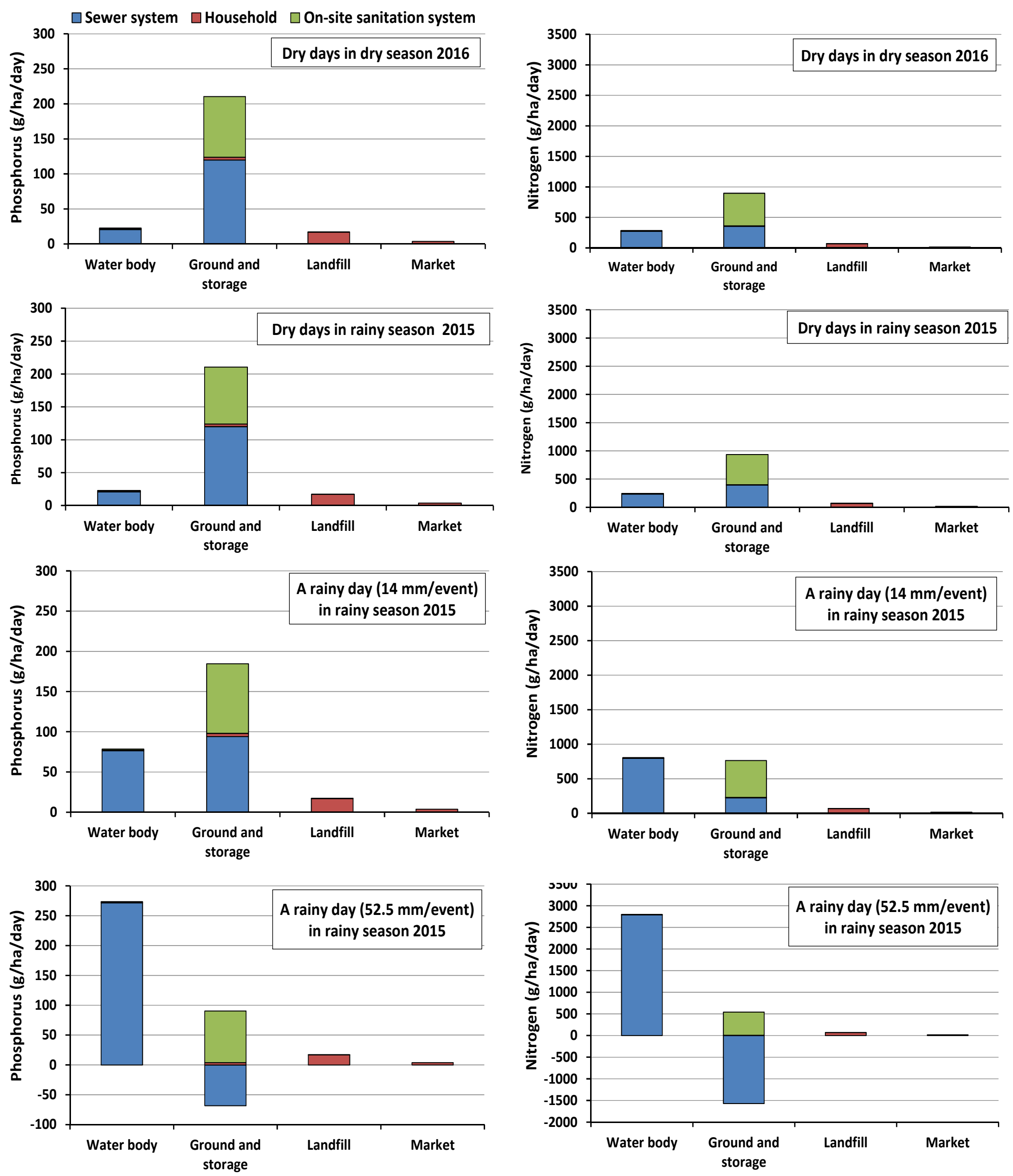

Figure 6-6 P and N destinations at different weather conditions (g/(ha·day))

6.4 Conclusions

In this study, P and N flow models were developed to quantify the P and N flows in an urban area and to clarify the impacts of domestic sewer discharge on P and N flows. The sewer system, which received various types of wastewater, was the majority source of P and N discharged into the water body. On dry days in dry season, P and N discharged from the sewer system accounted for 91.0% and 96.2% of total P and N came to the water body. The portion of contribution from the sewer system was higher on rainy days in rainy season (accounted for 99.2% and 99.6% of the total P and N came to the water body). It showed that the management of sewer discharge is very essential to manage the nutrient flows come to the water body.

The amount of P and N discharged into the water body varied strongly at different weather conditions. On dry days in dry season, P and N discharged to the water body only accounted for 14.7% (20.7 g P/(ha·day)) and 43.5% (273.5 g N/(ha·day)) of the total P and N inputted the sewer system. The amount of P and N discharged to the water body on dry days in rainy season were rather similar to dry days in dry season. On dry days in both dry season and rainy season, a great amount of P and N might accumulated inside the sewer system or exfiltrated into the ground. It is suggested that a further investigation should be implemented to separate the P and N accumulated inside the sewer system and the P and N flows came into the ground. On rainy days in rainy season, especially on high rainfall intensity days, the amount of P and N discharged into the water body increased greatly under the impact of rainfall. P and N discharged into the water body on these rainy days were higher 13.1 and 10.2 times than those on dry days in dry season. The amount of P and N outputted from the sewer system on these days was higher than the P and N inputted from households, on-site sanitation system and run-off flow. Accumulated sludge inside sewer pipes and/or water infiltrated from the ground were supposed to be the source which contributed to the P and N budget in the sewer system on heavy rainy days.

To mitigate the P and N load to surface water and groundwater, it is crucial to reduce the P and N load derived from the sewer system. In addition, an improvement of sewer system together with proper sewer sludge treatment is essential both for the prevention of groundwater contamination and surface water pollution.

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1. Anh, T. N. Q, Harada, H., Fujii, S., Lieu, P. K., and Tanaka, S. (2014) Waste management and its impacts in Hue Citadel: a phosphorus flow analysis, *23rd KAIST-KU-NTU-NUS Symposium*, July 2nd – 5th, Kyoto, Japan , page 88 - 95.
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Chapter 7 Conclusions and recommendations

7.1 Conclusions

The weak management of material flows in urban areas had led to a great amount of pollutant flows come to the environment and caused the serious pollution in most of urban areas in developing countries. A better management of materials, especially of nutrients is urgent need for the protection of urban environment as well as for the preservation of natural resources. By investigating the characteristics of domestic wastewater discharge and developing a water balance and material flow model for nutrients, the study supplied more necessary information on domestic wastewater discharge characteristics and clarified the impacts of domestic wastewater flow on the whole urban material flows. Thus, it can help to get a better understanding on domestic wastewater discharge and to find out solutions to well manage the material flows in urban areas. Some main results of this study are as follows.

Sewer system in the target drainage area received a large amount of greywater (from 94% of households) and toilet effluent (from 53% of households) generated inside the area. Average discharge flow rate at the sewer outlet on dry days in dry season was 2.72±0.32 m^3/h (44.9±5.4 L/cap/day) in 2015, and 2.27±0.44 m^3/h (37.5±7.3 L/cap/day) in 2016, which was about half of that on dry days in rainy season (4.99±0.55 m^3/h (82.5±9.1 L/cap/day) in 2015, and 5.38±2.15 m^3/h (88.9±35.5 L/cap/day) in 2014). Discharge flow rate varied among hours during 24 hours in a day and basically corresponded to a water consumption trend in the study area. The high discharge flow rate was from 6:00 - 16:00 and from 16:00 - 0:00, and the lowest discharge occurred in the early morning (1:00 - 6:00). Discharge flow rate was different among dry days in dry season in 2016 ($P<0.05$). On weekends the discharge flow rate (2.47±0.38 m^3/h) slightly higher than that on weekdays (2.21±0.45 m^3/h) ($P<0.05$). On rainy days in rainy season, discharge flow rate was affected by rainfall intensity. Stronger rainfall intensities corresponded to higher discharge flow rates. Only rainfall intensities higher than 1 mm/h might cause the impact on discharge flow rate.

The study supplied information on concentration of SS, VSS, BOD_5, COD_{Cr}, TN, NH_4^+, and TP in the sewer discharge at the outlet on dry days in both dry season and rainy season, and on rainy days in rainy season. Sewer discharge quality on dry days in dry season was characterized by low concentrations of SS, nutrients, and organic matter, which demonstrated that domestic wastewater in urban Hue was not strongly polluted. Dissolved pollutants were dominant than particulate matter at the outlet, which might cause by the in-sewer settling process due to low velocity of flow. Discharge concentrations did not strongly fluctuate among hour on a dry day. On rainy days in rainy season, pollutants concentrations were highest at the beginning time of rain events when the rainfall intensity reached at around 7.5 mm/h, which was observed as the first flush phenomenon. After that, although rainfall and flow rate kept increasing, pollutants concentrations decreased to very low levels as the result from dilution effect caused by large flows. Because of the dilution effect, pollutant concentrations decreased many times (3 – 10 times) lower than those on dry days.

Pollution loads from the sewer system to water body on dry days in dry season were rather similar to those on dry days in rainy season. Unit loads were many times lower than those in other areas, which might reflect the characteristic of living condition in urban Hue. Hourly pollution loads at the outlet on dry days in dry season showed the same pattern for all parameters in both dissolved phase and particulate phase, which were resembled the pattern of hourly discharge flow rate in a day. On rainy days in rainy seasons, pollution loads increased very high during rainy time. Peaks of pollution loads were 15 times to 400 times higher than the average loads on dry days in dry season. Dissolved matter mainly contributed to the total load on dry days while particulate matter has a great contribution to total load during time of rain. The L-Q equations showed that SS and VSS loads tended to increase the most greatly with the discharge flow rate, followed by COD_{Cr} and BOD_5, TP and TN. NH_4^+ was the parameter showed the lowest increase with the increase of flow rate.

Water balances of the sewer system were similar for all dry days in both dry season and rainy season in which water exfiltrated from the sewer system into the ground. On rainy days in rainy season, water balance seemed show different patterns for different rainfall intensity days. On dry days in dry season, only 28.5% (in 2016) – 34.0% (in 2015) of total wastewater inputted the sewer system reached at the outlet to discharge to the water body. This means that a large remaining amount of wastewater was loss during the transportation time in sewer system. This wastewater could have been exfiltrated into the underground though sewer leakage.

Phosphorus (P) and nitrogen (N) flow models were developed in the target drainage area on dry days in dry season 2016 (DdDs), dry days in rainy season 2015 (DdRs), and two different rainfall intensities day in rainy season 2015. On dry days in dry season, the sewer system received a similar amount of P in greywater from households (73.1 g P/(ha·day) – 52.0% of total P input to sewer system) and in effluent from on-site sanitation systems (67.6 g P/(ha·day) – 48.0% of total P input to sewer system). Meanwhile, N came to sewer system was mainly from on-site sanitation effluent (506.5 g N/(ha·day) – 80.6% of total N input to sewer system). Greywater from households only accounted for 19.4% of total N came to sewer system. Sewer system was identified as the main component contributed P (91.0% - 99.2%) and N (95.6% - 99.6%) to the water body in both dry season and rainy season. Therefore, a well management of sewer discharge will help to reduce the nutrient flows come to the water body.

The amount of P and N discharged into the water body varied strongly at different weather conditions. On dry days in dry season, P and N discharged to the water body only accounted for 14.7% (20.7 g P/(ha·day)) and 43.5% (273.5 g N/(ha·day)) of the total P and N inputted the sewer system. A similar amount of P and N discharged to the water body was observed on dry days in rainy season. On rainy days in rainy season, under the impact of rainfall, P and N amount discharged into the water body increased greatly and many times higher than those on dry days. The higher amount of P and N discharged at the sewer outlet than the total P and N inputted on heavy rainy days showed that there were other sources of P and N contributed to the total budget of P and N on rainy days. These sources might be accumulated sludge inside the sewer pipes and/or water infiltrated the sewer system from the ground.

7.2 Recommendations for further studies

In sewer survey, firstly we selected a V-Notch weir to measure the sewer discharge flow rate and after that we used flow sensor in combination with V-Notch. At current condition of our sewer system, it might be the most suitable way to monitor flow rate continuously since the flow velocity in sewer pipes in dry season was very small while the velocity increased very high on rainy days in rainy season. However, this method still had some limitations since the installation of V-Notch might cause some impacts on survey results, such as it slowed down the flow velocity and created the condition for water stored and particulate matter settled down in front of the weir. It is suggested that we should consider more carefully the experimental set up so that the impacts of V-Notch on the results could be minimized. For example, the wastewater samples should be collected at the forward position placement of V-Notch to prevent the impact of V-Notch on the discharge quality identification.

In this study, flow rates on rainy days were estimated by using a reference equation with the optimized value of head correction factor and might not reflect the exact amount of discharge. Therefore, it is necessary to carry out an actual measurement of discharge flow rate at different rainfall intensities in the near future to establish an equation to recalculate the discharge flow rate on rainy days.

Information on sewer discharge in this study can be used for designing of wastewater treatment facilities in the near future. The amount of sewage flow, quality and loads discharged at the sewer outlet in our drainage area were rather small compared to those of the input flows of the system as well as those in other areas. In-sewer processes, such as sewer leakage and settling process, were suspected to impact on the sewer discharge at the outlet. Therefore, it is suggested that in-sewer processes should be examined more detail in further studies. This kind of information is very useful for the improvement of sewerage system.

From the results of material flow analysis, a large amount of nutrients (P and N) did not discharge at the sewer outlet on dry days. This amount of nutrients might accumulated inside the sewer system and/or came into the ground through sewer leakage. It is very important to quantify the amount of nutrients in sewer sludge and went to the ground to have an appropriate solution of management. Since this study mainly focused on quantifying the nutrients came to the surface water, further studies on quantifying the nutrients came to the ground should be conducted to clarify the impact of sewage on soil and groundwater.

Furthermore, in the development the material flow model in our study, many data from references were used to calculate the flows. However, from our survey on sewer system component, we found that the values of these flows in our study area were rather different with other areas. Therefore, it is better to conduct actual measurements for other flows, especially important flows such as greywater from households, effluent from on-site sanitation system, and run-off water from street to validate the model.

APPENDIX

Appendix I (A)

Questionnaire of wastewater discharge in target drainage area (Chapter 4)

BẢNG CÂU HỎI KHẢO SÁT
QUESTIONNAIRE SHEET

Người phỏng vấn: ______________________________ Ngày phỏng vấn: _____ /____ /_____
Name of interviewer — Date of interview

Họ và tên người được phỏng vấn: ______________________________
Name of interviewee
Địa chỉ: ____ Phường: ____________
Address — Ward
Tuổi: _____ Giới tính: Nam/Nữ Nghề nghiệp: ____________
Age — Sex: Male/Female — Occupation
Quan hệ với chủ hộ: ____________
Relationship to the house owner

A-THÔNG TIN CHUNG VỀ HỘ GIA ĐÌNH
Household attribution

1. Số người hiện đang sinh sống tại gia đình: _____ người. Giới tính: _____ Nam _____ Nữ
   No. of people often lives in the house — Sex structure — Male — Female

2. Độ tuổi:
   Age structure

□ <5 _____ người	□ 20-29 _____ người	□ 50-59 _____ người
□ 5-9 _____ người	□ 30-39 _____ người	□ 60-69 _____ người
□ 10-19 _____ người	□ 40-49 _____ người	□ >69 _____ người

3. Thu nhập trung bình hàng tháng của cả gia đình: ____________ VNĐ/tháng
   Average monthly income of the family — VNĐ/month

4. Hoạt động kinh doanh:
   Commercial activity
   □ Có, gia đình tự kinh doanh — □ Không
   Yes, carried out by the family — No
   □ Gia đình cho người khác thuê mặt bằng để kinh doanh
   Yes, carried out by other people who rent one part of the house for business

   Nếu có, xin cho biết:
   If yes, please answer the below questions
   4.1. Loại hình kinh doanh: ____________________________
   Type of commercial activity

   4.2. Thời gian kinh doanh trong ngày: _____ giờ - _____ giờ
   Time of commercial activity carried out in a day

   4.3. Hoạt động kinh doanh có tiêu thụ nước không? □ Có □ Không
   Does the commercial activity consume water — Yes — No

4.4. Nếu có, nguồn nước lấy từ đâu? __________________
If yes, the water source is

4.5. Lượng nước sử dụng cho hoạt động kinh doanh: _____ (m^3/tháng) /hoặc _____ (VNĐ/tháng)
Amount of water consumed for commercial activity m^3/month VNĐ/month

4.6. Nước thải từ hoạt động kinh doanh thải đi đâu? ____________________________________
Where does wastewater from commercial activities go to

B- HOẠT ĐỘNG SỬ DỤNG NƯỚC CHO SINH HOẠT
Domestic water consumption activities

5. Nguồn nước sử dụng cho sinh hoạt của gia đình:
Please indicate water sources and corresponding purposes

Nguồn/Source	Mục đích/Purpose			
☐ Nước máy Tap water	☐ Ăn/Cooking ☐ Lau nhà/House cleaning	☐ Uống/Dringking ☐ Tưới cây/Gardening	☐ Tắm/Bathing ☐ Khác/Other	☐ Giặt/Laundry
☐ Nước giếng Well water	☐ Ăn/Cooking ☐ Lau nhà/House cleaning	☐ Uống/Dringking ☐ Tưới cây/Gardening	☐ Tắm/Bathing ☐ Khác/Other	☐ Giặt/Laundry
☐ Nước mưa Rain water	☐ Ăn/Cooking ☐ Lau nhà/House cleaning	☐ Uống/Dringking ☐ Tưới cây/Gardening	☐ Tắm/Bathing ☐ Khác/Other	☐ Giặt/Laundry
☐ Nước đóng chai Bottled water	☐ Ăn/Cooking ☐ Lau nhà/House cleaning	☐ Uống/Dringking ☐ Tưới cây/Gardening	☐ Tắm/Bathing ☐ Khác/Other	☐ Giặt/Laundry

6. Lượng nước sử dụng cho sinh hoạt mỗi tháng: _____ (m^3/tháng) /hoặc _________ (VNĐ/tháng)
Amount of water consumed per month m^3/month or VNĐ/month

7. Hoạt động sử dụng nước cho sinh hoạt:
Domestic water using behavior

7.1. Giặt áo quần/Washing style: ☐ Giặt máy/By washing machine ☐ Giặt tay/By hands

7.2. Tắm rửa/Bathing:
☐ Dùng bồn tắm/Use bath-tub ☐ Dùng vòi hoa sen/Use shower ☐ Dùng gáo dội/Use bucket

7.3. Rửa thực phẩm/Cooking: ☐ Dùng bồn rửa/Use kitchen sink ☐ Dùng thau rửa/Use plastic basin

7.4. Rửa chén bát/Dishes washing: ☐ Dùng bồn rửa/Use kitchen sink ☐ Dùng thau rửa/Use plastic basin

7.5. Loại bồn cầu sử dụng/Toilet type:
☐ Bệ ngồi, loại 1 nút xả nước (Normal cistern-flush) ☐ Bệ ngồi, loại 2 nút xả nước (Water-saving cistern-flush) ☐ Ngồi xổm, dội nước bằng tay (Pour-flush)

C-QUẢN LÝ NƯỚC THẢI HỘ GIA ĐÌNH
Wastewater management

8. Nước thải sinh hoạt (tắm, giặt, nấu ăn,…) thải đi đâu?
Where does grey water go to

☐ Xả trực tiếp ra cống thoát nước thành phố (Directly to a sewer network) ☐ Xả vào bể tự hoại (To a septic tank) ☐ Xả ra sân vườn (To surface ground)

□ Xả ra hố ga của nhà trước khi ra cống
To a manhole before to sewer network

□ Xả ra sông/hồ gần nhà
To a lake/river nearby

9. Nước đầu ra của bể tự hoại thải đi đâu?
Where does septic tank effluent go to

□ Xả trực tiếp ra cống thoát nước thành phố
Directly to a sewer network

□ Xả ra sân vườn
To underground

□ Xả ra hố ga của nhà trước khi ra cống
To a manhole before to sewer network

□ Xả ra sông/hồ gần nhà
To a lake/river nearby

D-QUẢN LÝ BỂ TỰ HOẠI
Septic tank management

10. Nhà ông bà có xây dựng bể tự hoại không: □ Có □ Không
Is there a septic tank in your house Yes No

11. Nếu có, xin hãy mô tả bể tự hoại của nhà ông/bà:
If yes, please describe the septic tank

11.1. Hình dạng của bể: □ Bể hình hộp □ Bể hình trụ
Shape of septic tank Rectangular Cylinder

11.2. Số ngăn: □ 1 □ 2 □ 3
No. of chamber

11.3. Vật liệu xây bể: □ Bê tông □ Khác (ghi rõ)
Material Concrete Other (indicate)

11.4. Năm xây bể:_____
Year of construction

12. Vận hành và quản lý bể tự hoại:
Septic tank operation and management

12.1. Chất thải đưa vào bể tự hoại: □ Chất thải từ nhà vệ sinh □ Nước thải sinh hoạt (tắm, giặt,…)
Influence to septic tank Toilet effluent Grey water

12.2. Bể tự hoại nhà ông/bà đã từng được hút bao giờ chưa? □ Đã từng hút rồi □ Chưa bao giờ
Has septic tank ever been desludged Yes No

12.3. Nếu đã từng hút, số lần hút: ______ lần. Lần hút gần đây nhất: ______
If yes, No. of desludging times. Latest desludging

Appendix I (B1)

Structured interview result - Household's characteristic (Chapter 4)

HH	HH Size	Age structure									Main job	HH Ave. Income (VND/month/HH)
		< 5	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50 - 59	60 - 69	> 69		
1	3				1			1	1		Small trader	8,000,000
2	4		1			1	1		1		Teacher	10,000,000
3	6			1	1		2		2		Worker	10,000,000
4	8	1		1	2		1	1	2		Worker	12,000,000
5	2						1	1			House keeper	6,000,000
6	1							1			House keeper	9,000,000
7	2							2			Jobholder	9,000,000
8	4	1			1	1	1				Small trader	25,000,000
9	4				2			2			Teacher	12,000,000
10	4		1				2		1		Teacher	13,000,000
11	4				1	1			1	1	Small trader	14,000,000
12	4			2		1	1				Small trader	10,000,000
13	3			1				1	1		Driver	10,000,000
14	6		2			2			1	1	Jobholder	12,000,000
15	4			1					3		Jobholder	6,000,000
16	11	2	1	1	1	3		1	1	1	Small trader	15,000,000
17	6			1	1		2			2	Small trader	12,000,000
18	5				3			2			Worker	14,000,000
19	2						2				Small trader	8,000,000
20	4					2		2			Retired	10,000,000
21	5	1	1			2				1	Jobholder	9,000,000
22	5			1	1		1	1		1	Small trader	10,000,000
23	4					1	1	1		1	Jobholder	10,000,000
24	10	1	1	2	1	1	1	3			Worker	10,000,000
25	2								1	1	Retired	8,000,000
26	3					2				1	Teacher	6,000,000
27	4				1	1	1			1	Jobholder	25,000,000
28	6				4				1	1	Small trader	15,000,000
29	6	2				1	1		2		Small trader	15,000,000
30	5				3			2			Jobholder	12,000,000
31	2							1	1		Retired	4,000,000
32	5	2			1	1				1	Jobholder	12,000,000
33	3		1			1	1				Small trader	25,000,000
34	3					1			2		Retired	10,000,000
35	6			2			2			2	Jobholder	7,000,000
36	4	2				2					Small trader	7,000,000
37	6		1	2	1				2		Small trader	10,000,000
38	6	2		1	1		2				Small trader	6,000,000
39	5			2			2			1	Small trader	10,000,000
40	3				1		1	1			Small trader	5,000,000
41	10	2	1		5				2		Small trader	10,000,000
42	4			1			1	1	1		Jobholder	10,000,000
43	2				1					1	House keeper	3,000,000
44	7			1	2		1	1	2		Jobholder	21,000,000
45	7	1		1	1	2		2			Jobholder	16,000,000

HH	HH Size	Age structure									Main job	HH Ave. Income (VND/month/HH)
		< 5	5 - 9	10 - 19	20 - 29	30 - 39	40 - 49	50 - 59	60 - 69	> 69		
46	7	1	1		1	2			2		Jobholder	6,000,000
47	3		1			2					Teacher	13,000,000
48	5			1	2			2			Teacher	20,000,000
49	5	2				1	1		1		Small trader	7,000,000
50	5				3		2				Driver	4,000,000
51	1									1	House rental	20,000,000
52	2						1			1	House rental	15,000,000
53	4	2			2						Small trader	10,000,000
54	3					1			2		Retired	15,000,000
55	6	2	1			2			1		Small trader	20,000,000
56	6					3			2	1	Jobholder	10,000,000
57	5			2			1			2	Jobholder	12,000,000
58	3	1			1	1					Small trader	6,000,000
59	4					1			3		Officer	8,000,000
60	14	4		1	2	5			1	1	Jobholder	30,000,000
61	4			1		1				2	Teacher	5,000,000
62	5	1	1			2			1		Jobholder	12,000,000
63	3					1			2		Jobholder	8,000,000
64	10		2	2	1	2	2			1	Small trader	8,000,000
65	2								2		Retired	6,000,000
66	4					2			1	1	Jobholder	14,000,000
67	5			2				2		1	Worker	7,000,000
68	5		1	2			2				Tailor	10,000,000
69	4			2			2				Bicycle mechan	7,000,000
70	5	1			1	2				1	Teacher	10,000,000
71	4	1	1			2					Small trader	9,000,000
72	3			1			1	1			Small trader	5,000,000
73	4				2			2			Small trader	5,000,000
74	5				1	2		2			Small trader	10,000,000
75	5	1			1			2		1	Small trader	5,000,000
76	2							1		1	Small trader	4,000,000
77	4				2			2			Worker	7,000,000
78	4	2				2					Jobholder	8,000,000
79	6	1			2	1		2			Jobholder	12,000,000
80	2									2	Retired	2,000,000
81	3				1			2			Small trader	14,000,000
82	3			1		2					Baber	6,000,000
83	5				2	1		1	1		Jobholder	15,000,000
84	4	1				2				1	Small trader	15,000,000
85	11	3		1	4	1		2			Small trader	8,000,000
86	4				1	2		1			Small trader	12,000,000
87	10			5			3			2	Jobholder	20,000,000
88	3				1				2		Retired	5,000,000
89	9	2	1			2		2	1	1	Small trader	17,000,000
90	3				1				1	1	Retired	7,000,000
91	7	3				2			2		Jobholder	12,000,000
92	9	1	2		2	2			2		Jobholder	22,000,000
93	4				2			2			Small trader	10,000,000
94	6	1			3			2			Jobholder	10,000,000
95	6	1				3		2			Small trader	15,000,000
96	2								2		Small trader	5,000,000
97	3		1				2				Jobholder	8,000,000
98	5			2	3						Small trader	8,000,000
99	2					1			1		Small trader	3,000,000
100	5	2			1	2					Police	16,000,000

Appendix I (B2)

Structured interview result – Destination of greywater and OSS effluent (Chapter 4)

1- Directly to a sewer system	4- To a lake/river nearby
2- To a manhole before to sewer system	5- To a septic tank
3- To surface/underground	

HH	Have septic tank	Greywater discharge	OSS effluent discharge
1	No	1	3
2	No	1	3
3	Yes	3	3
4	Yes	1	1
5	Yes	1	3
6	Yes	1	3
7	Yes	1	3
8	Yes	1	3
9	No	1	3
10	Yes	1	3
11	No	1	3
12	Yes	1	2
13	Yes	1	2
14	No	1	3
15	Yes	2	2
16	Yes	1	2
17	Yes	2	1
18	Yes	1	3
19	Yes	1	1
20	Yes	2	1
21	Yes	4	4
22	Yes	1	1
23	Yes	1	3
24	Yes	1	1
25	Yes	1	1
26	Yes	1	1
27	Yes	1	1
28	Yes	1	1
29	Yes	2	1
30	Yes	1	2

HH	Have septic tank	Greywater discharge	OSS effluent discharge
31	Yes	1	3
32	Yes	1	3
33	Yes	1	1
34	Yes	2	3
35	No	3	3
36	Yes	1	2
37	No	1	3
38	Yes	1	1
39	Yes	2	1
40	No	1	3
41	No	1	3
42	No	3	3
43	Yes	3	3
44	Yes	2	1
45	No	2	3
46	Yes	2	1
47	Yes	2	1
48	Yes	2	1
49	No	1	3
50	No	1	3
51	Yes	2	1
52	No	1	3
53	No	1	3
54	Yes	1	1
55	No	1	3
56	Yes	1	1
57	Yes	1	1
58	Yes	1	1
59	No	1	3
60	No	3	3
61	No	1	3
62	No	1	3
63	No	1	3
64	Yes	1	3
65	Yes	1	2
66	Yes	1	1
67	No	1	3
68	Yes	1	3
69	No	2	3
70	No	2	3

HH	Have septic tank	Greywater discharge	OSS effluent discharge
71	No	2	3
72	No	2	3
73	No	2	3
74	Yes	2	1
75	Yes	1	3
76	No	1	3
77	Yes	1	2
78	Yes	2	1
79	No	2	3
80	Yes	2	1
81	Yes	2	3
82	Yes	2	2
83	Yes	1	3
84	Yes	1	1
85	Yes	2	2
86	Yes	1	2
87	Yes	1	1
88	Yes	2	1
89	Yes	2	2
90	Yes	2	2
91	Yes	2	2
92	Yes	2	2
93	Yes	2	2
94	Yes	2	2
95	Yes	2	2
96	Yes	2	2
97	Yes	2	2
98	Yes	1	1
99	Yes	2	2
100	Yes	2	2

Appendix I (C)

Water consumption amount per capita (obtained from recording water meters) (Chapter 4)

2015/07/22														
House No.	Street	No. of people	0-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12
79	Nhật Lệ	6	0.00	0.00	0.00	0.00	0.00	11.79	19.85	19.30	7.70	3.59	6.04	8.24
81	Nhật Lệ	3	0.00	0.00	0.00	0.00	0.00	23.57	59.33	6.73	0.04	0.04	0.61	0.05
99	Nhật Lệ	3	8.73	0.00	0.00	0.00	0.00	0.00	2.07	1.72	0.33	3.34	0.00	2.44
1/83	Nhật Lệ	3	0.00	0.00	0.67	0.00	2.38	0.11	2.52	1.25	1.68	0.18	0.29	0.45
3/83	Nhật Lệ	4	1.50	0.00	0.00	0.00	0.00	0.14	12.67	8.15	1.46	2.82	2.07	3.96
4/83	Nhật Lệ	4	0.00	0.00	1.24	0.00	0.00	3.37	24.94	10.64	0.77	5.68	0.22	0.65
5/83	Nhật Lệ	5	5.75	0.00	0.00	0.00	3.59	0.01	1.53	0.48	2.42	0.06	0.01	2.76
11/83	Nhật Lệ	4	8.55	0.00	0.00	0.00	0.00	4.27	20.55	19.17	0.01	0.02	0.01	0.02
75	Nguyễn Biểu	7	0.00	0.00	0.00	0.00	7.20	5.70	10.53	4.53	12.81	16.33	3.77	10.35
77	Nguyễn Biểu	5	0.00	0.28	0.00	0.00	1.64	4.29	7.15	7.74	22.88	10.70	6.89	12.15
78	Nguyễn Biểu	14	5.25	0.00	0.00	0.00	0.00	3.00	4.07	0.13	0.72	2.29	2.31	3.87
80	Nguyễn Biểu	4	11.88	0.00	8.45	0.00	0.00	0.02	4.26	9.84	0.37	4.85	3.28	6.63
84	Nguyễn Biểu	5	8.97	0.00	0.00	0.00	0.00	0.27	15.26	1.57	0.22	0.25	0.22	1.32
86	Nguyễn Biểu	4	9.83	0.00	0.00	0.00	0.00	2.50	0.04	0.08	0.02	0.56	0.27	0.09
68	Đặng Dung	5	0.74	0.00	0.00	0.00	0.69	7.69	6.73	5.67	10.04	9.33	12.10	6.92
70	Đặng Dung	5	0.22	0.00	0.00	0.00	0.00	0.16	0.58	2.31	0.06	0.43	0.08	0.04
25	Đoàn Thị Điểm	8	1.60	0.00	0.00	0.00	0.00	0.41	0.56	0.20	0.23	0.09	0.55	0.68
33	Đoàn Thị Điểm	4	8.75	0.00	0.00	0.00	0.00	0.14	3.13	3.70	3.04	5.57	7.69	4.58
39	Đoàn Thị Điểm	3	3.26	0.00	0.00	0.00	0.00	4.70	8.36	3.43	2.37	3.77	6.09	15.63
47	Đoàn Thị Điểm	5	0.64	0.00	0.00	0.00	2.34	4.48	7.36	1.28	13.14	2.42	16.83	0.58
48	Đoàn Thị Điểm	6	1.86	0.00	0.00	0.00	0.22	0.28	14.34	7.01	1.22	5.11	3.21	26.70
62	Đoàn Thị Điểm	6	0.60	0.00	0.30	0.00	0.00	1.10	3.17	3.80	5.05	1.26	0.10	0.04
64	Đoàn Thị Điểm	5	2.83	0.00	0.00	0.00	2.04	4.07	3.94	2.44	6.15	3.80	2.69	6.05

2015/07/22														
House No.	**Street**	**No. of people**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**
79	**Nhật Lệ**	**6**	6.70	1.06	3.95	3.53	7.80	6.30	2.94	6.37	25.00	20.32	1.70	0.64
81	**Nhật Lệ**	**3**	0.05	0.02	0.36	0.36	0.03	0.76	22.27	46.36	17.22	0.03	0.00	0.00
99	**Nhật Lệ**	**3**	1.80	16.58	11.84	2.53	1.27	4.59	0.00	1.43	1.26	2.83	0.06	0.00
1/83	**Nhật Lệ**	**3**	0.63	1.21	1.64	1.37	1.34	1.75	1.67	0.49	6.49	2.91	0.09	0.00
3/83	**Nhật Lệ**	**4**	3.92	0.06	3.12	0.93	5.08	9.45	15.05	0.66	2.73	9.86	0.10	4.26
4/83	**Nhật Lệ**	**4**	0.00	1.72	0.01	10.44	1.69	0.36	4.39	8.28	0.01	6.65	1.44	5.27
5/83	**Nhật Lệ**	**5**	2.67	1.25	0.02	8.28	1.43	2.07	4.74	0.32	0.61	7.63	0.01	3.57
11/83	**Nhật Lệ**	**4**	0.26	4.65	0.01	0.00	0.02	15.38	4.90	1.29	2.41	1.83	0.01	1.24
75	**Nguyễn Biểu**	**7**	6.94	6.13	6.76	5.06	1.22	9.07	1.19	0.10	0.05	12.88	1.94	1.64
77	**Nguyễn Biểu**	**5**	8.11	21.70	3.52	10.05	10.68	21.96	10.70	1.52	1.03	3.22	0.03	0.00
78	**Nguyễn Biểu**	**14**	0.89	1.08	1.20	3.88	2.83	2.11	4.17	8.72	8.59	4.97	1.77	0.70
80	**Nguyễn Biểu**	**4**	4.71	9.67	14.22	0.00	9.44	4.35	1.51	9.08	10.35	22.76	0.00	3.06
84	**Nguyễn Biểu**	**5**	0.19	2.42	0.16	0.11	2.93	5.88	12.85	34.33	16.98	0.96	23.25	0.00
86	**Nguyễn Biểu**	**4**	0.10	0.00	0.14	0.23	0.21	0.03	0.02	0.01	0.00	0.00	0.00	0.00
68	**Đặng Dung**	**5**	4.13	1.56	2.03	25.60	0.91	7.97	10.62	23.72	19.80	5.23	0.39	0.41
70	**Đặng Dung**	**5**	0.07	0.22	0.18	0.69	0.58	1.93	0.06	3.62	0.01	0.00	0.19	0.02
25	**Đoàn Thị Điểm**	**8**	0.49	0.05	0.05	0.61	0.36	0.18	2.25	0.93	0.95	0.36	0.09	1.53
33	**Đoàn Thị Điểm**	**4**	0.38	0.79	4.80	6.18	0.62	7.60	3.34	13.01	0.26	0.00	0.08	0.90
39	**Đoàn Thị Điểm**	**3**	15.39	2.28	7.94	5.95	3.80	28.27	10.41	5.25	58.58	11.39	6.86	2.19
47	**Đoàn Thị Điểm**	**5**	2.06	7.26	4.70	0.09	0.07	17.70	5.19	8.21	2.24	0.10	0.10	2.22
48	**Đoàn Thị Điểm**	**6**	0.12	0.28	0.21	2.94	2.95	9.35	1.64	6.23	9.45	3.25	0.03	1.01
62	**Đoàn Thị Điểm**	**6**	2.04	0.70	0.27	2.64	3.26	2.68	6.17	0.01	3.58	2.96	2.17	1.36
64	**Đoàn Thị Điểm**	**5**	0.97	6.54	7.71	6.13	20.58	15.77	0.09	2.60	8.70	3.78	2.50	2.12

2015/07/23														
House No.	Street	No. of people	0-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12
79	Nhật Lệ	6	0.00	0.00	0.00	0.00	0.00	3.06	8.26	7.69	20.58	15.59	21.09	6.97
81	Nhật Lệ	3	0.00	0.00	0.00	0.00	0.01	0.34	9.47	7.84	2.19	0.04	0.04	0.57
99	Nhật Lệ	3	0.23	0.37	0.00	0.00	1.64	0.01	0.01	3.11	0.55	4.61	0.00	0.04
1/83	Nhật Lệ	3	0.00	0.00	1.32	0.00	0.00	0.00	1.39	0.73	0.03	1.60	1.81	1.58
3/83	Nhật Lệ	4	1.66	0.00	0.00	0.00	0.00	0.16	4.83	14.77	1.67	3.08	13.02	1.56
4/83	Nhật Lệ	4	1.05	0.00	0.00	0.00	1.84	1.71	14.46	4.51	0.00	0.76	0.04	0.01
5/83	Nhật Lệ	5	0.91	0.00	0.00	0.15	0.00	0.00	1.84	1.30	0.70	4.65	0.85	3.70
11/83	Nhật Lệ	4	0.00	0.48	0.75	0.00	0.00	6.73	45.63	0.01	1.29	0.00	10.08	13.04
75	Nguyễn Biểu	7	0.71	0.00	0.00	0.00	0.00	5.55	12.28	12.55	11.40	4.59	16.21	12.84
77	Nguyễn Biểu	5	4.41	0.00	0.00	0.00	3.30	8.86	4.91	30.16	3.71	5.30	11.35	11.40
78	Nguyễn Biểu	14	0.62	0.00	0.00	0.00	0.00	3.16	3.21	2.78	13.31	4.29	4.95	16.84
80	Nguyễn Biểu	4	3.32	0.00	0.00	0.00	2.85	5.13	6.56	6.45	4.25	1.94	10.37	5.83
84	Nguyễn Biểu	5	0.88	0.00	0.00	0.00	0.00	0.09	21.72	17.67	4.11	2.43	0.93	26.73
86	Nguyễn Biểu	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	Đặng Dung	5	1.18	0.00	0.00	0.00	0.77	16.61	12.51	23.10	27.60	0.61	2.41	7.46
70	Đặng Dung	5	0.00	0.00	0.00	0.00	0.00	0.47	0.19	0.69	0.20	2.22	0.88	2.23
25	Đoàn Thị Điểm	8	0.67	0.00	0.00	0.00	0.00	0.01	0.57	0.28	0.73	0.89	0.37	0.52
33	Đoàn Thị Điểm	4	0.00	0.00	5.03	0.00	0.00	3.39	1.55	12.61	1.76	6.77	4.44	0.31
39	Đoàn Thị Điểm	3	0.00	0.00	0.00	0.00	0.64	0.80	13.87	1.67	4.13	5.29	20.23	7.66
47	Đoàn Thị Điểm	5	10.52	1.49	0.00	0.00	0.00	4.45	2.26	1.98	4.44	7.64	5.17	0.50
48	Đoàn Thị Điểm	6	0.75	0.00	0.00	0.00	0.00	1.95	2.18	18.09	3.31	5.39	13.91	8.73
62	Đoàn Thị Điểm	6	0.71	0.00	0.00	0.00	1.81	3.33	4.66	0.84	7.26	1.32	1.67	8.45
64	Đoàn Thị Điểm	5	0.73	0.00	0.00	0.00	1.75	9.14	4.62	10.40	9.90	5.17	2.93	6.39

2015/07/23														
House No.	**Street**	**No. of people**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**
79	**Nhật Lệ**	**6**	5.73	5.90	9.04	8.19	5.70	5.28	11.41	15.00	15.15	9.82	15.30	7.90
81	**Nhật Lệ**	**3**	0.04	0.09	0.00	0.01	0.19	0.47	3.61	33.59	11.24	17.95	1.85	1.32
99	**Nhật Lệ**	**3**	0.73	0.47	6.60	4.77	2.93	3.80	7.89	1.25	1.58	3.48	0.00	0.00
1/83	**Nhật Lệ**	**3**	0.98	1.13	1.41	1.41	1.30	1.26	3.37	0.30	4.96	2.02	0.00	0.00
3/83	**Nhật Lệ**	**4**	0.22	3.90	2.36	6.06	4.19	6.59	3.43	11.07	4.33	0.61	0.00	0.00
4/83	**Nhật Lệ**	**4**	0.00	0.00	0.00	0.00	0.00	0.00	3.24	7.21	3.19	1.72	1.45	1.98
5/83	**Nhật Lệ**	**5**	1.81	38.71	0.75	0.03	8.92	2.20	10.00	5.28	0.10	11.18	0.28	1.58
11/83	**Nhật Lệ**	**4**	3.90	2.10	0.08	11.27	11.50	0.01	11.63	9.45	0.84	2.90	1.00	1.18
75	**Nguyễn Biểu**	**7**	6.37	0.99	9.30	0.44	1.83	7.39	11.91	5.42	0.21	5.57	0.14	0.00
77	**Nguyễn Biểu**	**5**	7.82	6.89	4.06	19.72	26.96	12.10	4.68	2.31	4.81	1.47	37.94	0.00
78	**Nguyễn Biểu**	**14**	7.01	3.80	3.48	6.68	2.64	3.30	2.35	10.02	6.85	1.59	0.36	0.35
80	**Nguyễn Biểu**	**4**	6.75	9.00	0.00	8.01	1.04	12.88	13.48	14.37	7.78	9.16	52.18	18.75
84	**Nguyễn Biểu**	**5**	12.64	1.46	3.88	4.57	0.56	1.20	6.43	12.56	4.86	22.14	99.10	17.34
86	**Nguyễn Biểu**	**4**	0.00	0.00	0.00	0.04	0.00	0.12	25.10	0.01	0.04	0.02	0.00	0.00
68	**Đặng Dung**	**5**	2.18	1.12	5.83	10.14	13.17	1.72	9.48	11.79	0.31	7.28	0.16	0.63
70	**Đặng Dung**	**5**	1.25	0.02	0.66	0.19	0.08	0.22	2.42	4.46	1.64	0.34	0.64	0.37
25	**Đoàn Thị Điểm**	**8**	0.06	0.09	0.02	0.04	0.20	2.23	0.17	1.39	2.20	0.48	0.10	0.24
33	**Đoàn Thị Điểm**	**4**	0.00	3.93	2.56	8.00	0.48	0.91	11.43	5.99	0.00	0.00	0.00	0.00
39	**Đoàn Thị Điểm**	**3**	2.77	3.77	6.37	0.74	1.44	30.71	19.84	13.58	58.21	23.19	0.44	0.15
47	**Đoàn Thị Điểm**	**5**	3.79	0.16	0.66	7.36	6.31	14.46	4.37	1.97	10.12	0.00	0.00	0.00
48	**Đoàn Thị Điểm**	**6**	3.77	9.13	0.26	2.30	0.30	14.36	10.70	10.64	0.44	0.21	4.06	1.04
62	**Đoàn Thị Điểm**	**6**	2.16	2.11	1.46	19.43	0.84	7.07	4.85	0.36	2.68	2.32	1.27	0.67
64	**Đoàn Thị Điểm**	**5**	3.08	6.35	5.92	24.66	9.43	13.05	9.73	4.14	9.92	4.90	4.04	0.25

2015/07/18														
House No.	Street	No. of people	0-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12
79	Nhật Lệ	6	0.40	0.54	0.00	0.00	0.00	3.50	9.76	27.88	20.36	7.54	8.74	7.41
81	Nhật Lệ	3	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	3.00	20.44
99	Nhật Lệ	3	1.64	0.00	0.00	0.00	0.00	0.00	0.00	5.57	1.55	4.55	0.48	0.02
1/83	Nhật Lệ	3	0.00	0.20	0.00	0.00	0.44	0.16	2.11	1.15	0.63	1.94	0.96	0.46
3/83	Nhật Lệ	4	4.12	0.00	0.00	0.00	0.00	24.96	9.29	7.56	9.40	4.40	14.48	6.08
4/83	Nhật Lệ	4	0.00	0.57	0.00	0.00	1.08	0.54	5.26	13.90	0.73	2.59	0.01	0.62
5/83	Nhật Lệ	5	0.00	0.00	0.01	0.00	0.00	0.04	0.01	2.12	3.25	0.06	0.16	4.63
11/83	Nhật Lệ	4	0.17	0.00	0.00	0.00	0.00	0.01	1.08	1.90	0.00	0.04	0.02	0.03
75	Nguyễn Biểu	7	0.00	0.00	0.00	0.00	0.71	5.41	17.37	13.54	21.57	4.82	5.77	0.18
77	Nguyễn Biểu	5	0.63	0.00	0.00	0.00	10.38	12.33	4.27	12.78	9.15	22.97	21.63	13.16
78	Nguyễn Biểu	14	5.63	0.00	0.00	0.00	0.00	4.61	4.37	6.14	10.35	6.12	1.88	2.85
80	Nguyễn Biểu	4	9.01	0.00	0.00	0.00	0.00	0.00	8.23	9.76	2.89	0.42	0.42	5.39
84	Nguyễn Biểu	5	9.94	0.00	0.00	0.00	1.60	4.56	19.04	0.29	0.74	8.46	1.25	4.55
86	Nguyễn Biểu	4	0.86	0.00	0.00	0.00	0.00	0.22	0.00	0.26	0.12	0.02	0.20	0.42
68	Đặng Dung	5	0.46	0.42	0.00	0.00	0.00	3.78	4.25	1.34	1.66	0.00	2.69	9.59
70	Đặng Dung	5	0.27	0.00	0.15	0.00	0.00	0.38	0.26	0.60	0.06	0.04	0.65	0.29
25	Đoàn Thị Điểm	8	4.14	0.00	0.00	0.00	0.00	0.78	0.72	0.41	0.30	0.20	0.17	0.21
33	Đoàn Thị Điểm	4	2.25	0.00	0.00	0.00	0.00	0.54	4.08	2.81	0.17	1.63	0.14	0.20
39	Đoàn Thị Điểm	3	13.68	13.39	0.00	0.00	0.00	3.57	7.57	9.03	0.69	1.07	4.33	14.11
47	Đoàn Thị Điểm	5	4.28	0.00	0.00	0.00	0.00	1.28	11.79	4.62	4.78	5.23	18.30	12.36
48	Đoàn Thị Điểm	6	2.79	0.00	0.00	0.00	0.00	0.05	0.99	15.91	3.23	5.49	3.04	8.86
62	Đoàn Thị Điểm	6	2.15	0.00	0.00	0.00	0.00	0.23	3.56	0.58	3.28	1.73	3.09	5.18
64	Đoàn Thị Điểm	5	0.50	0.00	0.00	0.00	0.00	2.96	9.04	1.03	1.04	6.08	2.36	1.44

2015/07/18														
House No.	**Street**	**No. of people**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**
79	**Nhật Lệ**	**6**	2.88	2.49	6.23	12.64	8.86	7.96	3.28	13.31	24.43	13.67	7.33	5.39
81	**Nhật Lệ**	**3**	5.89	0.00	3.81	0.01	0.00	3.18	8.95	0.63	0.00	0.00	0.39	0.00
99	**Nhật Lệ**	**3**	0.31	0.00	0.16	0.00	4.95	0.00	0.00	1.00	2.59	0.00	0.00	0.00
1/83	**Nhật Lệ**	**3**	1.56	1.21	0.18	4.23	1.15	0.69	1.87	0.99	2.78	0.36	0.00	0.00
3/83	**Nhật Lệ**	**4**	1.36	1.32	30.50	3.83	1.88	10.68	16.64	10.20	0.30	1.25	3.11	1.42
4/83	**Nhật Lệ**	**4**	2.38	3.85	21.84	0.01	5.20	0.38	56.73	25.87	40.19	59.71	5.25	0.73
5/83	**Nhật Lệ**	**5**	1.99	0.00	7.16	0.07	0.02	2.34	3.90	11.36	4.21	0.02	0.25	1.56
11/83	**Nhật Lệ**	**4**	0.01	0.01	0.03	33.57	6.89	12.08	0.02	17.41	11.18	1.07	0.00	0.00
75	**Nguyễn Biểu**	**7**	0.05	0.07	0.06	0.07	0.26	0.20	0.07	0.08	0.07	2.61	1.41	0.76
77	**Nguyễn Biểu**	**5**	1.11	13.82	0.84	3.29	2.59	30.63	33.03	8.68	0.22	0.73	2.06	1.72
78	**Nguyễn Biểu**	**14**	3.09	3.03	4.97	1.38	2.10	2.55	1.46	3.69	6.97	1.88	7.65	2.96
80	**Nguyễn Biểu**	**4**	1.79	2.55	2.65	3.11	1.17	12.70	5.69	6.23	5.34	3.03	17.93	2.94
84	**Nguyễn Biểu**	**5**	17.09	4.27	4.77	1.16	0.30	1.86	5.31	6.11	0.73	1.54	7.87	7.56
86	**Nguyễn Biểu**	**4**	0.05	0.22	0.00	0.17	0.00	0.45	0.08	0.16	0.14	0.28	25.00	7.09
68	**Đặng Dung**	**5**	0.90	5.63	3.76	0.01	2.70	3.57	18.50	20.66	5.16	2.84	0.77	0.48
70	**Đặng Dung**	**5**	0.52	1.12	0.00	0.04	0.25	0.15	2.52	0.20	0.14	0.62	0.15	0.00
25	**Đoàn Thị Điểm**	**8**	0.13	0.00	1.13	0.01	0.08	0.10	0.11	1.06	0.68	0.55	0.39	0.30
33	**Đoàn Thị Điểm**	**4**	0.00	7.11	1.74	0.06	2.89	1.48	4.44	0.68	7.89	0.20	2.25	0.35
39	**Đoàn Thị Điểm**	**3**	5.25	0.82	4.39	17.72	37.61	31.33	11.63	17.19	35.79	13.01	8.73	9.88
47	**Đoàn Thị Điểm**	**5**	5.41	9.89	0.77	0.85	1.44	11.63	9.52	6.92	3.07	2.67	1.03	0.36
48	**Đoàn Thị Điểm**	**6**	0.11	4.01	7.84	11.37	0.13	2.03	7.47	0.87	0.23	9.12	0.04	0.45
62	**Đoàn Thị Điểm**	**6**	0.47	0.00	4.31	0.19	14.81	1.56	0.02	0.61	3.37	0.41	5.20	2.26
64	**Đoàn Thị Điểm**	**5**	4.18	1.88	3.70	0.00	7.00	10.04	1.00	24.85	1.08	4.19	2.50	2.66

2015/07/25														
House No.	Street	No. of people	0-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12
79	Nhật Lệ	6	0.00	0.00	1.77	1.75	3.55	3.64	30.57	28.93	5.69	10.03	21.15	20.78
81	Nhật Lệ	3	0.97	0.00	0.00	0.00	0.00	0.00	21.40	1.32	1.13	0.94	2.35	0.18
99	Nhật Lệ	3	1.27	0.00	0.00	0.00	0.00	0.33	2.56	1.30	1.11	1.83	0.94	0.83
1/83	Nhật Lệ	3	0.00	0.00	0.00	0.00	0.17	0.00	5.26	0.64	1.99	0.00	2.34	0.97
3/83	Nhật Lệ	4	2.23	0.52	0.00	0.00	0.00	1.99	1.95	3.14	9.10	5.47	4.56	2.57
4/83	Nhật Lệ	4	2.16	0.00	0.00	0.00	14.77	16.33	4.37	1.60	1.57	1.49	0.69	0.46
5/83	Nhật Lệ	5	0.00	0.00	0.00	0.72	0.00	0.04	1.61	10.13	1.77	0.31	0.16	0.42
11/83	Nhật Lệ	4	3.44	0.00	0.00	0.00	0.00	1.36	5.29	1.06	0.00	1.86	0.02	0.00
75	Nguyễn Biểu	7	0.00	0.00	0.00	0.00	0.00	6.83	9.39	22.21	0.13	0.08	0.10	0.11
77	Nguyễn Biểu	5	0.00	0.00	0.00	0.00	6.72	47.58	8.44	18.72	34.16	6.42	7.76	20.21
78	Nguyễn Biểu	14	3.13	0.00	0.00	0.00	2.60	1.91	7.80	3.40	4.90	5.06	0.65	6.83
80	Nguyễn Biểu	4	3.53	0.00	0.00	0.00	13.64	18.76	1.72	1.33	2.82	4.63	0.71	7.51
84	Nguyễn Biểu	5	10.61	0.00	0.00	0.00	7.02	1.96	9.93	0.28	0.88	1.53	6.51	1.96
86	Nguyễn Biểu	4	6.84	12.21	0.00	0.00	0.00	0.01	0.40	0.04	0.02	0.07	0.13	0.06
68	Đặng Dung	5	0.26	0.00	0.00	0.00	0.00	0.01	2.42	0.36	5.42	1.53	3.32	1.02
70	Đặng Dung	5	0.00	0.00	0.74	0.00	0.00	0.06	0.93	0.68	0.34	0.04	0.75	0.40
25	Đoàn Thị Điểm	8	3.37	0.00	0.00	0.00	4.18	0.20	1.03	0.55	0.84	0.36	0.34	0.42
33	Đoàn Thị Điểm	4	0.00	0.00	0.00	0.00	5.32	6.68	8.68	4.85	7.02	0.00	3.91	5.48
39	Đoàn Thị Điểm	3	12.02	0.00	0.00	0.00	0.00	0.13	15.10	1.36	1.67	2.70	11.31	9.01
47	Đoàn Thị Điểm	5	2.58	0.00	1.09	0.00	0.00	0.69	1.77	4.92	7.92	0.72	5.22	2.13
62	Đoàn Thị Điểm	6	0.00	0.00	0.00	0.00	3.60	4.72	2.10	10.76	6.50	2.32	1.05	1.65
64	Đoàn Thị Điểm	5	1.99	0.00	0.00	0.00	0.00	3.20	2.63	1.88	6.63	3.57	4.78	3.30

2015/07/25														
House No.	Street	No. of people	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
79	Nhật Lệ	6	12.14	5.10	8.34	1.33	7.44	5.60	3.05	5.02	25.80	12.41	13.23	7.56
81	Nhật Lệ	3	0.21	0.14	0.09	0.15	0.00	0.84	0.48	0.00	31.38	7.21	0.98	0.11
99	Nhật Lệ	3	1.89	1.37	0.97	1.98	1.41	0.40	0.00	0.57	0.96	0.19	3.15	2.51
1/83	Nhật Lệ	3	0.72	0.46	2.51	0.77	0.54	0.86	5.94	0.16	4.65	0.36	3.88	3.65
3/83	Nhật Lệ	4	2.77	0.09	4.48	7.51	4.90	7.49	14.49	1.09	5.58	3.08	0.75	3.24
4/83	Nhật Lệ	4	2.79	2.52	4.83	0.72	23.07	5.06	4.39	11.22	0.09	0.08	0.00	0.00
5/83	Nhật Lệ	5	0.06	0.25	0.79	0.56	3.51	20.06	15.29	9.36	9.83	3.41	0.04	0.00
11/83	Nhật Lệ	4	0.00	0.00	0.01	0.44	3.50	0.00	2.25	22.01	3.26	2.64	0.01	0.00
75	Nguyễn Biểu	7	0.06	0.05	0.03	0.07	0.04	0.04	0.05	0.05	0.07	22.56	12.24	8.45
77	Nguyễn Biểu	5	3.89	16.84	8.77	4.28	14.00	9.49	0.35	7.33	0.92	3.66	0.27	0.25
78	Nguyễn Biểu	14	1.25	0.61	0.89	1.80	1.68	0.22	7.04	3.06	4.40	0.52	0.58	0.41
80	Nguyễn Biểu	4	8.29	9.19	12.16	4.15	0.00	0.00	6.79	31.23	35.31	4.26	32.47	13.51
84	Nguyễn Biểu	5	64.01	1.29	6.53	0.88	0.86	4.56	1.95	1.37	14.48	13.09	25.18	10.68
86	Nguyễn Biểu	4	0.36	0.12	0.12	0.00	0.03	0.36	0.05	0.07	0.02	0.00	0.00	0.00
68	Đặng Dung	5	5.42	0.08	0.00	0.67	1.61	8.44	20.85	22.27	15.81	7.80	0.00	0.00
70	Đặng Dung	5	0.49	0.22	0.04	0.60	0.10	1.10	0.49	2.32	1.83	2.34	0.38	0.26
25	Đoàn Thị Điểm	8	0.10	1.90	1.78	0.26	0.22	0.32	0.37	0.57	0.63	1.59	0.09	0.00
33	Đoàn Thị Điểm	4	0.00	0.95	8.94	0.09	4.46	2.51	0.26	19.56	1.16	0.00	0.00	0.00
39	Đoàn Thị Điểm	3	3.13	3.95	4.16	3.27	3.72	9.64	16.62	18.17	45.21	7.89	9.81	3.84
47	Đoàn Thị Điểm	5	0.59	0.61	0.56	13.44	6.76	15.54	15.96	3.64	1.21	1.07	2.23	1.53
62	Đoàn Thị Điểm	6	3.07	3.40	1.07	0.20	2.80	2.50	1.55	0.26	0.01	1.91	7.60	3.35
64	Đoàn Thị Điểm	5	2.48	2.89	1.95	46.25	2.61	12.00	3.88	3.10	3.15	3.93	1.31	0.00

Appendix I (D1)

Head on the V-Notch weir and flow rate at the sewer outlet on dry days in dry season 2015 (Chapter 4)

Head on the weir (cm)				
	Weekday		Weekend	
Time	7/22/2015 (Wed.)	7/23/2015 (Thu.)	7/18/2015 (Sat.)	7/25/2015 (Sat.)
1:00	3.5	4.5	4	4.5
2:00	3.5	4	3.5	3
3:00	2.5	3.5	3	3
4:00	2	3.5	3	2
5:00	2	3	2.5	2
6:00	2.5	3.5	2.5	3.5
7:00	3	3.5	2.5	3.5
8:00	4	4	3.5	4
9:00	4.5	4.5	5	4.5
10:00	4.5	4.5	5	4.5
11:00	5	4.5	5	5.5
12:00	5	5	5	5.5
13:00	5	5	4.5	5.5
14:00	5	5	4.5	5.5
15:00	5	5	4.5	5.5
16:00	5	5	4.5	5
17:00	4.5	4.5	4.5	4.5
18:00	4.5	5	4.5	4.5
19:00	5.5	5.5	4.5	5.5
20:00	5.5	5.5	4.5	5.5
21:00	6	5.5	4.5	6
22:00	5.5	5.5	5	6
23:00	5.5	5.5	5	5.5
0:00	5.5	5	4.5	5.5
1:00	4.5	3.5	4.5	5

Flow rate (m^3/h) on dry days in dry season 2015				
	Weekday		Weekend	
Time	22/7/2015 (Wed.)	23/7/2015 (Thu.)	18/7/2015 (Sat.)	25/7/2015 (Sat.)
1:00	1.36	2.36	1.84	2.38
2:00	1.22	1.77	1.22	0.70
3:00	0.37	1.29	0.85	0.78
4:00	0.26	1.29	0.85	0.19
5:00	0.39	0.91	0.51	0.52
6:00	0.70	1.43	0.57	1.56
7:00	1.12	1.43	0.71	1.43
8:00	2.13	2.06	1.71	2.06
9:00	2.66	2.66	3.62	2.66
10:00	2.67	2.59	3.40	2.75
11:00	3.47	2.67	3.40	4.49
12:00	3.40	3.47	3.32	4.34
13:00	3.40	3.40	2.51	4.34
14:00	3.40	3.40	2.59	4.34
15:00	3.40	3.40	2.59	4.26
16:00	3.32	3.32	2.59	3.24
17:00	2.51	2.59	2.59	2.51
18:00	2.75	3.55	2.59	2.75
19:00	4.49	4.42	2.59	4.49
20:00	4.42	4.34	2.59	4.42
21:00	5.42	4.34	2.67	5.51
22:00	4.26	4.34	3.47	5.34
23:00	4.34	4.26	3.32	4.26
0:00	4.18	3.10	2.51	4.26
1:00	2.36	1.14	2.59	3.32

Appendix I (D2)

Head on the V-Notch weir and flow rate at the sewer outlet on dry days in rainy season 2015 (Chapter 4)

Head on the weir (cm)				
Dry day				
Time	16/11/2015 (Mon.)	26/11/2015 (Thu.)	04/12/2015 (Fri.)	05/12/2015 (Sat.)
1:00	4.5	4.5	4.5	4.5
2:00	4.5	4.5	4.5	4
3:00	4.5	4	4.5	4
4:00	4.5	4	4	4
5:00	4.5	4.5	4.5	4
6:00	5.5	4.5	5	5
7:00	6	5	6	5.5
8:00	6	5.5	6.5	6
9:00	6.5	5.5	6.5	6.5
10:00	6.5	5.5	6.5	6.5
11:00	6.5	6	6.5	6.5
12:00	6.5	7	7	6.5
13:00	6.5	6	6.5	6.5
14:00	6	5.5	6.5	6.5
15:00	6	5.5	6	6.5
16:00	6.5	6	6.5	7
17:00	6	5.5	6.5	6.5
18:00	6	5.5	7	7
19:00	6.5	6	6	6.5
20:00	6	6	6	6
21:00	5.5	5.5	6	6
22:00	6	5	6.5	6
23:00	6	5.5	6.5	6.5
0:00	5.5	5.5	5.5	5.5
1:00	5	5	4.5	4.5

Flow rate (m^3/h) on dry days in rainy season 2015				
Time	16/11/2015 (Mon.)	26/11/2015 (Thu.)	04/12/2015 (Fri.)	05/12/2015 (Sat.)
1:00	2.59	2.59	2.59	2.36
2:00	2.59	2.52	2.59	1.84
3:00	2.59	1.84	2.52	1.91
4:00	2.59	1.99	1.91	1.91
5:00	2.75	2.66	2.74	2.06
6:00	4.57	2.67	3.63	3.62
7:00	5.51	3.55	5.67	4.50
8:00	5.51	4.42	6.75	5.59
9:00	6.75	4.34	6.66	6.75
10:00	6.66	4.42	6.66	6.66
11:00	6.66	5.68	6.75	6.66
12:00	6.66	8.06	8.06	6.66
13:00	6.58	5.17	6.58	6.66
14:00	5.34	4.26	6.58	6.66
15:00	5.51	4.42	5.42	6.75
16:00	6.66	5.42	6.75	8.06
17:00	5.34	4.26	6.75	6.66
18:00	5.51	4.42	7.97	8.06
19:00	6.66	5.51	5.25	6.49
20:00	5.26	5.34	5.42	5.34
21:00	4.34	4.18	5.51	5.42
22:00	5.51	3.40	6.75	5.51
23:00	5.34	4.42	6.50	6.58
0:00	4.18	4.26	4.02	4.02
1:00	3.32	3.32	2.36	2.44

Appendix I (D3)

Head on the V-Notch weir and flow rate at the sewer outlet and corresponded rainfall intensity in rain events in rainy season 2015 (Chapter 4)

24 Nov. 2015 (Tue.)			
Time	Head on the weir (cm)	Flow rate (m^3/h)	Rainfall intensity (mm/h)
4:40	4.0	1.75	0.0
5:00	5.0	3.13	3.0
5:20	13.0	114.25	7.5
5:40	20.5	353.53	9.0
6:00	26.0	637.39	7.5
6:20	29.0	835.64	13.5
6:40	20.0	332.53	1.5
7:00	15.0	162.92	0.0
7:20	--	--	0.0
7:40	--	--	0.0
8:00	8.0	34.27	0.0
8:20	--	--	0.0
8:40	--	--	0.0
9:00	6.5	6.20	0.0

27 Nov. 2015 (Fri.)			
Time	Head on the weir (cm)	Flow rate (m^3/h)	Rainfall intensity (mm/h)
7:00	5.5	4.01	0.0
7:20	--	--	0.0
7:40	--	--	0.0
8:00	5.5	4.01	0.0
8:20	--	--	0.0
8:40	--	--	0.0
9:00	6.0	5.03	0.0
9:20	6.0	5.03	0.0
9:40	6.5	6.20	3.0
10:00	17.5	238.78	7.5
10:20	19.5	312.29	3.0
10:40	28.5	800.36	7.5
11:00	30.0	908.94	6.0
11:20	--	--	18.0
11:40	--	--	18.0
12:00	30.5	946.97	21.0
12:20	--	--	16.5
12:40	--	--	13.5
13:00	30.5	946.97	25.5
13:20	--	--	3.0
13:40	--	--	1.5
14:00	23.0	470.28	4.5
14:20	--	--	6.0
14:40	--	--	1.5
15:00	22.5	445.33	0.0
15:20	--	--	0.0
15:40	--	--	0.0
16:00	12.0	93.68	1.5
16:20	--	--	0.0
14:40	--	--	0.0
17:00	10.5	67.27	0.0
17:20	--	--	0.0
17:40	--	--	0.0
18:00	9.5	52.48	0.0
18:20	--	--	0.0
18:40	--	--	0.0
19:00	8.5	39.83	0.0

29 Nov. 2015 (Sun.)			
Time	Head on the weir (cm)	Flow rate (m^3/h)	Rainfall intensity (mm/h)
13:00	10.5	67.27	0.0
13:20	--	--	0.0
13:40	--	--	0.0
14:00	10.5	67.27	0.0
14:30	10.5	67.27	4.0
14:50	13.5	125.46	3.0
15:10	15.0	162.92	0.0
15:30	14.5	149.78	1.5
16:00	12.5	103.66	0.0
16:20	--	--	0.0
16:40	--	--	0.0
17:00	10.5	67.27	0.0
17:20	--	--	0.0
17:40	--	--	0.0
18:00	9.5	52.48	0.0

6 Dec. 2015 (Sun.)			
Time	**Head on the weir (cm)**	**Flow rate (m^3/h)**	**Rainfall intensity (mm/h)**
10:40	10.0	59.60	0.0
11:00	10.0	59.60	3.0
11:20	17.5	238.78	10.5
11:40	30.0	908.94	1.5
12:00	20.5	353.53	3.0
12:20	28.0	765.99	4.5
12:40	28.0	765.99	3.0
13:00	--	--	1.5
13:20	--	--	0.0
13:40	14.5	149.78	0.0
14:00	--	--	3.0
14:20	--	--	3.0
14:40	21.5	397.85	6.0
15:00	--	--	0.0
15:20	--	--	1.5
15:40	15.5	176.72	0.0
16:00	--	--	1.5
16:20	--	--	3.0
16:40	20.0	332.53	3.0
17:00	--	--	4.5
17:20	--	--	0.0
17:40	19.0	292.81	0.0
18:00	--	--	3.0
18:20		--	0.0
18:40	15.5	176.72	0.0
19:00	--	--	1.5
19:20	--	--	0.0
19:40	12.0	93.68	0.0
20:00	--	--	0.0
20:20	--	--	0.0
20:40	11.5	84.30	1.5
21:00	--	--	0.0
21:20	--	--	0.0
21:40	10.5	67.27	0.0

Appendix I (D4)

Head on the V-Notch weir and flow rate at the sewer outlet on dry days and rainy days in rainy season 2014

(Chapter 4)

Head of the weir in rainy season 2014 (cm)							
	Dry day					Rainy day	
Time	01/11/2014 (Sat.)	2/11/2014 (Sun.)	10/11/2014 (Mon.)	19/11/2014 (Wed.)	21/11/2014 (Fri.)	14/11/2014 (Sat.)	22/11/2014 (Sat.)
1:00	--	--	--	--	--	--	--
2:00	--	--	--	--	--	--	--
3:00	--	--	--	--	--	--	--
4:00	--	--	--	--	--	--	--
5:00	--	--	--	--	--	--	--
6:00	--	--	--	--	--	--	--
7:00	6.9	5.0	4.4	6.6	4.5	8.1	5.3
8:00	6.9	5.9	4.5	7.0	5.2	7.6	13.3
9:00	7.4	6.1	4.5	6.6	5.9	7.4	14.1
10:00	7.4	6.1	4.9	6.1	5.6	7.9	9.2
11:00	7.4	6.4	4.9	6.1	5.4	7.4	8.6
12:00	7.4	6.4	5.2	7.0	5.3	7.7	7.6
13:00	7.6	6.3	5.4	7.0	5.6	7.6	7.1
14:00	7.6	5.4	5.2	6.6	5.4	8.1	6.1
15:00	7.4	5.4	4.2	6.6	5.4	7.4	6.1
16:00	6.9	5.5	4.0	6.1	5.4	7.1	6.1
17:00	6.4	5.4	4.2	5.9	5.4	7.4	6.4
18:00	6.6	5.5	4.9	6.4	5.4	7.4	6.4
19:00	7.6	5.4	4.9	5.9	5.6	7.4	6.6
20:00	7.6	5.4	4.9	6.3	5.2	7.1	6.4
21:00	5.9	5.4	4.9	5.9	5.2	6.6	5.9
22:00	--	--	--	--	--	--	--
23:00	--	--	--	--	--	--	--
0:00	--	--	--	--	--	--	--
1:00	--	--	--	--	--	--	--

Flow rate in rainy season 2014 (m3/h)							
	Dry day					Rainy day	
Time	01/11/2014 (Sat.)	2/11/2014 (Sun.)	10/11/2014 (Mon.)	19/11/2014 (Wed.)	21/11/2014 (Fri.)	14/11/2014 (Sat.)	22/11/2014 (Sat.)
1:00	--	--	--	--	--	--	--
2:00	--	--	--	--	--	--	--
3:00	--	--	--	--	--	--	--
4:00	--	--	--	--	--	--	--
5:00	--	--	--	--	--	--	--
6:00	--	--	--	--	--	--	--
7:00	7.77	3.54	2.46	7.00	2.70	35.34	3.64
8:00	7.86	5.37	2.61	8.06	3.98	30.18	120.90
9:00	9.38	5.69	2.65	6.77	5.26	28.25	139.74
10:00	9.30	5.71	3.29	5.57	4.46	33.22	48.47
11:00	9.30	6.45	3.27	5.81	4.09	28.25	41.00
12:00	9.33	6.39	3.83	8.21	3.98	31.17	30.18
13:00	9.99	5.98	4.14	7.99	4.56	30.18	25.49
14:00	9.92	3.99	3.57	6.86	4.11	35.34	5.25
15:00	9.17	4.15	1.99	6.84	4.14	28.25	5.25
16:00	7.59	4.34	1.91	5.54	4.14	25.49	5.25
17:00	6.35	4.14	2.30	5.25	4.14	28.25	5.95
18:00	7.14	4.34	3.33	6.40	4.17	28.25	5.95
19:00	10.13	4.12	3.22	5.18	4.51	28.25	6.45
20:00	9.66	4.14	3.22	6.15	3.69	25.49	5.95
21:00	4.90	4.14	3.22	5.13	3.76	6.45	4.82
22:00	--	--	--	--	--	--	--
23:00	--	--	--	--	--	--	--
0:00	--	--	--	--	--	--	--
1:00	--	--	--	--	--	--	--

Appendix I (D5)

Rainfall intensity on survey days in rainy season 2014 (Chapter 4)

Precipitation (mm/h)							
Time	**01/11/2014 (Sat.)**	**2/11/2014 (Sun.)**	**10/11/2014 (Mon.)**	**19/11/2014 (Wed.)**	**21/11/2014 (Fri.)**	**14/11/2014 (Sat.)**	**22/11/2014 (Sat.)**
6:00	0	0	0	0	0	0	0
07:00	0	0	0	0	0	0	0
08:00	0	0	0	0	0	0	2.7
09:00	0	0	0	0	0	0.1	0.7
10:00	0	0	0	0	0	0	0.2
11:00	0	0	0	0	0	0	0.7
12:00	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0.1	0.1
14:00	0	0	0	0	0	0.9	0
15:00	0	0	0	0	0	0.2	0
16:00	0	0	0	0	0	0.3	0
17:00	0	0	0	0	0	0	0
18:00	0	0	0	0	0	0	0
19:00	0	0	0	0	0	0	0
20:00	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0
Total	0	0	0	0	0	1.6	4.4

Appendix I (E1)

Sewage concentration at the sewer outlet on dry days in dry season 2015 (Chapter 4)

SS (mg/L)				
	Weekday		Weekend	
Time	7/22/2015 (Wed.)	7/23/2015 (Thu.)	7/18/2015 (Sat.)	7/25/2015 (Sat.)
1:00	31.7	31.8	32.4	28.6
2:00	20.0	28.4	31.6	26.5
3:00	18.4	29.6	29.2	20.6
4:00	17.0	29.4	18.3	17.5
5:00	10.5	20.2	16.2	16.7
6:00	35.5	29.1	32.0	22.5
7:00	33.7	22.1	41.7	20.9
8:00	42.7	24.8	44.8	20.2
9:00	32.9	24.8	41.1	21.1
10:00	36.1	25.4	33.2	23.7
11:00	34.4	35.5	35.8	24.0
12:00	30.2	34.5	34.0	26.7
13:00	42.2	37.3	46.0	13.6
14:00	45.4	50.0	50.0	39.3
15:00	67.0	43.3	44.1	34.8
16:00	58.0	43.7	42.7	31.2
17:00	62.4	42.3	45.4	37.7
18:00	65.0	31.1	42.3	40.0
19:00	37.2	28.3	60.4	47.3
20:00	35.3	35.7	39.3	46.4
21:00	45.3	32.0	61.0	51.2
22:00	35.0	36.0	39.3	35.8
23:00	34.3	29.7	56.3	31.7
0:00	39.7	26.9	40.5	35.6
1:00	31.8	34.1	45.4	30.3

VSS (mg/L)				
	Weekday		Weekend	
Time	7/22/2015 (Wed.)	7/23/2015 (Thu.)	7/18/2015 (Sat.)	7/25/2015 (Sat.)
1:00	31.4	30.7	30.0	26.7
2:00	13.1	27.4	29.8	25.7
3:00	10.2	24.4	28.2	18.2
4:00	8.9	27.8	17.3	15.1
5:00	7.5	19.6	14.6	15.3
6:00	31.8	26.7	30.8	20.5
7:00	29.3	20.7	39.7	18.0
8:00	35.0	23.8	26.1	16.7
9:00	29.3	22.3	33.1	18.9
10:00	31.9	23.0	28.2	20.5
11:00	27.5	27.2	32.0	18.8
12:00	27.2	31.7	17.3	20.0
13:00	37.8	30.0	28.3	12.0
14:00	41.4	36.8	34.4	33.3
15:00	59.0	34.3	38.4	24.4
16:00	53.3	37.0	38.0	17.2
17:00	40.0	37.7	39.5	30.0
18:00	59.6	24.2	36.0	32.6
19:00	31.8	24.0	48.6	41.3
20:00	31.3	29.1	28.3	42.3
21:00	41.7	19.5	51.0	43.4
22:00	29.5	23.7	22.3	32.2
23:00	30.9	25.0	53.0	25.0
0:00	36.6	25.3	39.0	27.2
1:00	30.7	26.7	43.7	29.0

BOD5 (mg/L)												
	Weekday						Weekend					
	7/22/2015 (Wed.)			7/23/2015 (Thu.)			7/18/2015 (Sat.)			7/25/2015 (Sat.)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1:00	64.2	49.2	15	96.6	84.8	11.8	110	72.4	37.6	73.2	63.3	9.9
5:00	109	78	31	67.8	58.5	9.3	101.8	84.8	17	66.3	51	15.3
9:00	104	86	18	72.6	55.5	17.1	98.2	79	19.2	54	34.2	19.8
13:00	107.4	93.8	13.6	101.1	83.7	17.4	122.8	105.6	17.2	81	63	18
17:00	112	98	14	90.9	69.6	21.3	121.8	105	16.8	70.2	54.6	15.6
21:00	100.8	87.6	13.2	109.5	90.9	18.6	100.8	81.6	19.2	72.3	61.8	10.5
1:00	96.6	84.8	11.8	85.8	74.1	11.7	91.4	76.6	14.8	65.7	55.2	10.5

COD (mg/L)												
	Weekday						Weekend					
	7/22/2015 (Wed.)			7/23/2015 (Thu.)			7/18/2015 (Sat.)			7/25/2015 (Sat.)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1:00	140.3	96.1	44.2	150.8	117.2	33.7	177.2	125.6	51.6	132.9	106.6	26.3
3:00	117.2	75.1	42.1	131.9	96.1	35.8	168.7	147.7	21.1	90.8	57.2	33.7
5:00	165.6	99.3	66.3	111.9	86.6	25.3	169.8	144.5	25.3	121.4	71.9	49.5
7:00	170.8	126.6	44.2	108.7	70.8	37.9	171.9	127.7	44.2	116.1	86.6	29.5
9:00	148.7	101.4	47.4	123.5	85.6	37.9	159.3	109.8	49.5	94.0	65.6	28.4
11:00	179.3	116.1	63.2	144.5	90.8	53.7	169.8	123.5	46.3	161.4	118.2	43.2
13:00	171.9	125.6	46.3	147.7	91.9	55.8	171.9	121.4	50.5	149.8	117.2	32.6
15:00	174.0	146.6	27.4	163.5	105.6	57.9	177.2	156.1	21.1	126.6	101.4	25.3
17:00	177.2	141.4	35.8	149.8	115.1	34.7	169.8	124.5	45.3	135.1	92.9	42.1
19:00	165.6	125.6	40.0	128.7	87.7	41.1	168.7	147.7	21.1	144.5	95.1	49.5
21:00	171.9	139.3	32.6	166.6	120.3	46.3	165.6	123.5	42.1	137.2	94.0	43.2
23:00	172.9	131.9	41.1	168.7	130.8	37.9	161.4	131.9	29.5	141.4	108.7	32.6
1:00	150.8	117.2	33.7	152.9	118.2	34.7	152.9	135.1	17.9	127.7	98.2	29.5

NH4 (mg/L)												
	Weekday						Weekend					
	7/22/2015 (Wed.)			7/23/2015 (Thu.)			7/18/2015 (Sat.)			7/25/2015 (Sat.)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1:00	16.0	13.6	2.3	26.3	22.5	3.8	34.5	31.9	2.6	22.6	20.5	2.0
3:00	15.6	14.4	1.3	25.3	24.1	1.2	38.4	37.2	1.2	16.8	13.7	3.2
5:00	28.8	27.3	1.5	22.4	18.1	4.3	39.9	37.1	2.8	19.9	16.0	3.9
7:00	30.2	25.8	4.4	25.5	21.0	4.5	44.4	38.9	5.6	29.8	26.9	2.9
9:00	31.7	26.9	4.7	31.6	28.6	3.0	39.3	33.7	5.5	26.4	24.3	2.1
11:00	37.5	33.9	3.6	29.8	27.5	2.3	44.3	41.6	2.6	33.7	27.4	6.3
13:00	25.8	22.6	3.3	30.7	26.2	4.4	35.8	33.9	1.9	28.7	24.4	4.3
15:00	29.5	26.6	2.9	33.1	29.3	3.8	37.6	35.2	2.4	21.3	17.2	4.1
17:00	36.0	33.9	2.2	29.4	25.9	3.5	42.7	40.9	1.8	24.0	17.4	6.6
19:00	32.0	28.8	3.3	30.4	24.8	5.6	44.4	37.7	6.8	31.3	23.6	7.6
21:00	31.7	29.9	1.8	31.8	28.1	3.7	38.4	33.0	5.4	30.3	23.0	7.3
23:00	35.3	32.8	2.5	29.8	25.4	4.4	34.4	31.3	3.0	26.4	21.0	5.4
1:00	26.3	22.5	3.8	24.5	22.1	2.4	35.6	33.0	2.6	23.3	21.0	2.3

TP (mg/L)												
	Weekday						Weekend					
	7/22/2015 (Wed.)			7/23/2015 (Thu.)			7/18/2015 (Sat.)			7/25/2015 (Sat.)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1:00	1.9	1.4	0.5	3.5	2.6	0.9	3.8	2.9	0.9	2.7	2.2	0.5
3:00	1.7	1.1	0.7	3.2	2.5	0.7	3.5	2.3	1.2	2.4	1.4	1.0
5:00	2.8	1.9	0.8	2.6	2.1	0.5	3.8	3.0	0.9	2.0	1.1	0.9
7:00	2.9	2.0	0.9	3.1	2.1	1.0	4.0	3.1	1.0	1.8	1.3	0.5
9:00	3.2	2.6	0.6	3.5	2.8	0.7	4.0	3.2	0.9	2.5	1.5	1.0
11:00	3.7	3.0	0.7	3.5	2.6	0.9	4.7	4.0	0.7	3.6	3.0	0.6
13:00	3.3	2.5	0.8	3.7	1.9	1.7	4.2	3.2	1.0	3.3	2.0	1.3
15:00	3.8	2.7	1.1	4.5	3.7	0.8	3.3	1.9	1.4	3.3	2.7	0.7
17:00	4.3	3.1	1.2	3.7	3.0	0.7	4.3	3.5	0.8	3.5	2.2	1.3
19:00	3.4	2.8	0.6	3.4	2.6	0.8	4.4	3.3	1.1	3.2	2.5	0.7
21:00	3.4	2.3	1.1	3.4	2.3	1.1	3.7	2.9	0.9	2.9	2.3	0.6
23:00	3.7	2.8	0.9	3.5	2.9	0.6	3.7	3.1	0.5	3.1	2.2	0.8
1:00	3.5	2.6	0.9	3.4	2.8	0.6	3.4	2.4	1.0	2.9	2.3	0.6

Appendix I (E2)

Sewage concentration at the sewer outlet on a dry day in rainy season 2015 (Chapter 4)

16 Nov. 2015					
Time	**Temp. (^{0}C)**	**pH**	**EC (mS/cm)**	**SS (mg/L)**	**VSS (mg/L)**
1:00	28.0	6.80	0.43	22.0	16.4
2:00	27.0	6.80	0.41	20.2	12.2
3:00	27.5	6.90	0.37	18.4	12.2
4:00	28.0	6.90	0.32	13.8	10.4
5:00	27.5	6.90	0.3	12.8	10.4
6:00	28.0	7.00	0.32	14.8	12.4
7:00	28.0	7.10	0.36	15.2	13.8
8:00	28.0	7.10	0.36	15.8	14.8
9:00	28.0	7.20	0.45	23.6	21.6
10:00	28.0	7.00	0.45	32.2	30.4
11:00	28.0	7.00	0.44	37.5	34.0
12:00	28.0	7.00	0.42	28.3	25.3
13:00	28.0	6.90	0.47	40.0	37.5
14:00	28.0	7.00	0.48	32.7	27.5
15:00	28.0	6.90	0.46	38.0	34.6
16:00	28.0	6.90	0.45	25.2	19.8
17:00	28.0	7.10	0.47	27.8	26.6
18:00	27.5	7.20	0.54	19.0	15.4
19:00	27.5	7.00	0.49	26.4	23.6
20:00	27.5	7.00	0.46	37.0	36.6
21:00	27.0	6.90	0.46	29.2	26.6
22:00	27.0	7.00	0.47	31.8	28.6
23:00	27.5	6.90	0.47	33.4	29.0
0:00	28.0	6.80	0.49	45.5	37.7
1:00	28.0	6.90	0.44	26.8	22.2

16 Nov. 2015	BOD (mg/L)			COD (mg/L)			NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1:00	32	23.4	8.6	88.6	76.6	12.0	11.48	11.13	0.35	17.75	13.57	4.18	1.32	1.00	0.32
3:00	--	--	--	83.6	69.6	14.0	7.91	6.30	1.61	10.04	8.67	1.37	1.17	0.75	0.41
5:00	14.8	11.4	3.4	33.6	28.6	5.0	5.61	4.12	1.50	8.00	6.63	1.37	1.02	0.70	0.31
7:00	--	--	--	52.6	37.6	15.0	13.89	11.48	2.42	15.93	12.36	3.57	1.48	1.15	0.33
9:00	45.2	36.4	8.8	105.6	76.6	29.0	16.07	14.94	1.13	19.07	15.17	3.90	1.98	1.56	0.41
11:00	--	--	--	111.6	79.6	32.0	17.00	15.73	1.27	23.64	20.02	3.63	1.79	1.47	0.32
13:00	65.1	54	11.1	119.6	98.6	21.0	16.31	15.39	0.92	19.29	16.49	2.80	1.83	1.65	0.18
15:00	--	--	--	74.6	56.6	18.0	15.43	12.21	3.22	17.03	13.30	3.74	2.15	1.49	0.66
17:00	43	33.6	9.4	108.6	75.6	33.0	18.04	16.31	1.73	27.06	20.02	7.04	2.23	1.63	0.61
19:00	--	--	--	107.6	92.6	15.0	22.51	18.16	4.35	34.38	26.63	7.76	2.45	1.60	0.84
21:00	48	36.5	11.5	117.6	95.6	22.0	16.39	13.49	2.90	21.99	16.55	5.44	2.07	1.32	0.75
23:00	--	--	--	113.6	95.6	18.0	22.51	15.10	7.41	27.44	18.64	8.80	2.19	1.58	0.61
1:00	36	26.2	9.8	93.6	77.6	16.0	12.86	11.36	1.50	19.02	13.68	5.33	1.44	1.05	0.39

Appendix I (E3)

Sewage concentration at the sewer outlet in rain events in rainy season 2015 (Chapter 4)

Rain event 24/11/2015					
Time	**Temp. (^{0}C)**	**pH**	**EC (mS/cm)**	**SS (mg/L)**	**VSS (mg/L)**
4:40	25.0	7.0	0.30	17.0	14.6
5:00	25.0	7.0	0.33	29.0	18.0
5:20	25.0	7.0	0.29	18.8	13.6
5:40	24.0	7.1	0.28	35.3	23.2
6:00	23.5	7.2	0.19	76.3	43.3
6:20	23.0	7.4	0.12	28.3	14.3
6:40	24.0	7.2	0.14	30.7	19.3
7:00	24.0	7.2	0.15	16.2	10.5
8:00	24.0	7.2	0.21	29.0	19.0
9:00	24.0	7.2	0.22	29.8	21.8

Rain event 24/11/2015	BOD (mg/L)			COD (mg/L)			NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Time	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**
4:40	20.9	17.2	3.7	39.6	31.8	7.8	3.10	2.64	0.46	8.11	6.80	1.31	0.84	0.71	0.13
5:00	29.0	19.6	9.4	39.6	26.3	13.3	2.87	2.18	0.69	8.77	8.34	0.43	1.23	1.01	0.21
5:20	27.7	17.8	9.9	35.6	24.8	10.8	2.53	2.07	0.46	7.94	6.25	1.70	1.18	0.90	0.28
5:40	24.8	12.9	11.9	31.6	16.3	15.3	2.18	1.61	0.57	7.23	5.09	2.14	1.17	0.80	0.37
6:00	18.8	17.0	1.8	23.6	8.3	15.3	1.61	1.38	0.23	6.29	2.44	3.85	0.87	0.44	0.43
6:20	6.2	3.8	2.4	18.6	3.3	15.3	0.34	0.23	0.11	2.82	1.18	1.64	0.38	0.17	0.20
6:40	9.5	5.7	3.8	22.6	4.3	18.3	0.80	0.69	0.11	3.32	1.56	1.75	0.52	0.20	0.32
7:00	9.8	7.3	2.5	24.6	11.3	13.3	0.92	0.80	0.11	4.86	2.11	2.74	0.55	0.31	0.25
8:00	25.4	16.4	9.0	38.6	23.8	14.8	4.59	4.36	0.23	6.73	5.53	1.20	0.87	0.65	0.22
9:00	35.8	29.0	6.8	60.6	40.3	20.3	6.09	5.51	0.57	11.03	9.00	2.03	0.92	0.77	0.15

Rain event 27/11/2015					
Time	Temp. (^{0}C)	pH	EC (mS/cm)	SS (mg/L)	VSS (mg/L)
7:00	25.0	7.0	0.30	12.6	8.0
8:00	25.0	7.2	0.41	19.0	13.2
9:00	25.0	7.1	0.45	21.8	15.8
9:20	25.0	7.2	0.45	21.4	15.6
9:40	24.0	7.2	0.45	23.2	18.6
10:00	24.0	7.2	0.34	34.4	24.4
10:20	23.0	7.3	0.28	65.4	43.2
10:40	23.0	7.5	0.18	61.8	37.5
11:00	22.0	7.3	0.13	52.7	25.7
12:00	22.5	7.6	0.07	23.3	14.4
13:00	21.0	7.4	0.05	21.4	11.2
14:00	21.0	7.2	0.09	12.0	9.4
15:00	22.0	7.2	0.14	9.6	8.0
16:00	22.0	7.2	0.23	10.0	7.6
17:00	23.0	7.2	0.28	26.0	20.0
18:00	23.0	7.1	0.34	12.8	8.4
19:00	23.5	7.0	0.38	16.2	10.3

Rain event 27/11/2015	BOD (mg/L)			COD (mg/L)			NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
7:00	18.7	14.8	3.9	47.6	29.3	18.3	11.60	11.14	0.46	16.43	13.30	3.13	1.61	1.25	0.36
8:00	53.1	36.0	17.1	82.6	51.8	30.8	18.95	18.84	0.11	24.47	22.17	2.30	2.07	1.79	0.27
9:00	66.1	47.3	18.8	103.6	69.8	33.8	19.41	17.34	2.07	26.29	23.60	2.69	2.08	1.67	0.42
9:20	59.7	39.3	20.4	102.6	67.8	34.8	19.41	18.95	0.46	26.62	24.98	1.64	2.09	1.60	0.49
9:40	64.3	41.1	23.2	112.6	74.3	38.3	20.22	19.18	1.03	27.50	24.70	2.80	2.08	1.72	0.36
10:00	62.4	41.0	21.4	109.6	84.8	24.8	16.20	15.28	0.92	22.54	17.21	5.33	1.88	1.40	0.48
10:20	65.5	32.0	33.5	101.6	56.8	44.8	10.45	9.88	0.57	19.07	11.97	7.10	1.58	0.95	0.63
10:40	56.0	22.7	33.3	100.6	43.3	57.3	6.32	5.86	0.46	11.85	6.80	5.06	0.98	0.60	0.38
11:00	47.3	16.3	31.0	87.6	28.3	59.3	1.19	0.92	0.28	5.24	0.30	4.95	0.56	0.13	0.43
12:00	22.9	9.0	13.9	32.6	13.3	19.3	1.01	0.83	0.18	2.10	0.08	2.03	0.30	0.02	0.28
13:00	18.9	6.6	12.3	26.6	9.8	16.8	0.64	0.55	0.09	2.66	0.19	2.47	0.33	0.09	0.24
14:00	9.5	5.4	4.1	14.6	8.3	6.3	0.92	0.64	0.28	4.20	2.00	2.19	0.30	0.18	0.12
15:00	8.2	4.6	3.6	13.6	4.8	8.8	1.38	1.10	0.28	3.43	2.22	1.20	0.27	0.19	0.08
16:00	9.4	6.8	2.6	21.6	15.3	6.3	5.19	4.50	0.69	8.55	5.97	2.58	0.48	0.37	0.11
17:00	13.9	11.4	2.5	22.6	20.8	1.8	5.42	5.24	0.18	7.34	6.08	1.26	0.58	0.43	0.15
18:00	21.3	16.0	5.3	31.6	18.8	12.8	6.43	6.16	0.28	7.23	5.31	1.92	0.70	0.42	0.28
19:00	22.1	16.7	5.4	38.6	20.8	17.8	8.27	7.72	0.55	8.71	8.01	0.71	0.94	0.50	0.44

Rain event 29/11/2015					
Time	**Temp. (^{0}C)**	**pH**	**EC (mS/cm)**	**SS (mg/L)**	**VSS (mg/L)**
13:00	24.0	7.1	0.49	14.6	10.8
14:00	24.5	7.1	0.48	10.0	7.0
14:30	24.0	7.0	0.48	13.8	9.5
14:50	24.0	7.1	0.46	25.3	22.8
15:10	24.0	7.1	0.43	12.8	8.8
15:30	24.0	7.0	0.44	18.7	16.0
16:00	24.0	7.1	0.40	12.5	9.2
17:00	24.0	7.1	0.43	11.7	9.5
18:00	24.0	7.1	0.44	13.0	9.8

Rain event 29/11/2015	BOD (mg/L)			COD (mg/L)			NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Time	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**	**Total**	**Dissolved**	**Particulate**
13:00	39.2	34.3	4.9	59.6	49.8	9.8	8.45	7.81	0.64	14.00	10.38	3.63	0.97	0.71	0.26
14:00	32.2	24.0	8.2	54.6	32.8	21.8	6.62	6.43	0.18	8.66	6.63	2.03	0.87	0.61	0.26
14:30	36.2	18.0	18.2	59.6	30.3	29.3	7.17	7.08	0.09	10.70	8.23	2.47	1.10	0.63	0.47
14:50	15.5	7.5	8.0	37.6	19.8	17.8	5.88	5.33	0.55	6.51	4.15	2.36	0.84	0.46	0.38
15:10	13.0	6.9	6.1	38.6	20.8	17.8	6.16	5.88	0.28	6.73	5.14	1.59	0.77	0.53	0.23
15:30	16.6	8.5	8.1	40.6	22.3	18.3	7.35	6.89	0.46	8.77	5.53	3.24	0.89	0.50	0.39
16:00	18.1	12.7	5.4	55.6	31.8	23.8	9.83	7.54	2.30	10.59	7.79	2.80	0.95	0.74	0.21
17:00	20.7	14.6	6.1	59.6	36.8	22.8	9.28	7.54	1.75	10.15	7.57	2.58	0.95	0.61	0.33
18:00	27.0	19.6	7.4	65.6	40.3	25.3	5.51	4.59	0.92	9.49	6.52	2.96	1.07	0.84	0.23

Rain event 6/12/2015					
Time	Temp. (^{0}C)	pH	EC (mS/cm)	SS (mg/L)	VSS (mg/L)
10:40	23.0	7.2	0.25	15.0	13.5
11:00	23.0	7.1	0.27	13.8	11.7
11:20	22.0	7.3	0.26	18.5	14.3
11:40	22.0	7.8	0.12	40.3	28.3
12:00	22.5	7.4	0.13	21.0	14.0
12:20	22.5	7.4	0.12	23.3	15.0
12:40	23.0	7.4	0.11	20.3	13.3
13:40	23.0	7.2	0.16	11.2	7.2
14:40	22.0	7.2	0.18	7.3	5.2
15:40	22.0	7.2	0.15	9.4	6.4
16:40	22.5	7.3	0.22	10.0	6.8
17:40	22.5	7.3	0.20	9.4	6.0
18:40	22.0	7.1	0.28	11.4	7.0
19:40	22.0	7.1	0.33	10.6	7.8
20:40	22.0	7.1	0.34	13.6	10.6
21:40	22.0	7.1	0.36	12.2	9.4

Rain event 6/12/2015	BOD (mg/L)			COD (mg/L)			NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
10:40	36.0	26.5	9.5	59.6	40.8	18.8	5.15	4.96	0.18	6.95	4.92	2.03	0.74	0.54	0.20
11:00	40.2	31.3	8.9	63.6	45.3	18.3	7.17	6.80	0.37	9.16	6.74	2.41	0.78	0.61	0.18
11:20	48.6	27.5	21.1	78.6	46.8	31.8	7.72	7.17	0.55	9.27	6.63	2.63	0.93	0.61	0.31
11:40	9.7	3.2	6.5	23.6	8.8	14.8	1.84	1.56	0.28	4.20	1.07	3.13	0.46	0.11	0.35
12:00	14.3	7.1	7.2	26.6	13.3	13.3	1.56	1.38	0.18	3.92	0.96	2.96	0.30	0.05	0.25
12:20	16.3	7.8	8.5	34.6	14.3	20.3	2.57	2.48	0.09	5.74	1.45	4.29	0.36	0.06	0.31
12:40	18.5	9.0	9.5	39.6	17.8	21.8	2.85	2.39	0.46	3.20	1.01	2.19	0.23	0.05	0.17
13:40	29.8	13.8	16.0	42.6	20.8	21.8	3.03	2.85	0.18	3.46	3.40	0.06	0.34	0.21	0.13
14:40	27.1	14.5	12.6	41.6	21.8	19.8	3.77	3.49	0.28	4.49	3.54	0.94	0.40	0.23	0.17
15:40	30.1	22.7	7.4	37.6	27.3	10.3	3.12	2.66	0.46	3.90	2.22	1.68	0.34	0.23	0.11
16:40	27.3	22.6	4.7	41.6	23.3	18.3	4.41	4.23	0.18	5.08	4.13	0.94	0.43	0.25	0.18
17:40	26.3	19.8	6.5	36.6	23.8	12.8	2.66	2.30	0.37	4.41	2.70	1.72	0.37	0.25	0.12
18:40	35.1	20.1	15.0	41.6	24.3	17.3	4.96	4.41	0.55	5.81	4.64	1.17	0.49	0.32	0.18
19:40	40.3	23.0	17.3	43.6	24.3	19.3	4.87	4.69	0.18	6.58	5.42	1.17	0.62	0.38	0.24
20:40	42.0	24.9	17.1	46.6	26.3	20.3	6.25	6.06	0.18	7.17	5.70	1.48	0.80	0.49	0.31
21:40	40.0	23.4	16.6	47.6	28.3	19.3	6.98	6.25	0.74	7.90	6.59	1.31	0.89	0.54	0.34

Appendix I (E4)

Sewage concentration at the sewer outlet on dry days in rainy season 2014 (Chapter 4)

	Temp. (^0C)		pH		EC (mS/cm)	
Time	**1/11/2014**	**19/11/2014**	**1/11/2014**	**19/11/2014**	**1/11/2014**	**19/11/2014**
6h	27.0	26.0	7.4	7.1	0.43	--
7h	27.5	26.5	7.4	7.2	0.42	--
8h	27.5	27.0	7.4	7.1	0.38	--
9h	27.5	27.0	7.4	7.1	0.38	--
10h	28.0	27.0	7.4	7.1	0.35	--
11h	27.5	27.0	7.4	7.1	0.35	--
12h	28.0	27.0	7.3	7.0	0.33	--
13h	29.0	27.0	7.4	7.0	0.31	--
14h	29.0	27.0	7.4	7.1	0.29	--
15h	28.0	27.0	7.4	7.1	0.3	--
16h	28.0	26.5	7.4	7.1	0.29	--
17h	28.0	26.0	7.5	7.2	0.29	--
18h	28.0	26.0	7.5	7.1	0.28	--
19h	28.0	26.5	7.4	7.1	0.27	--
20h	28.0	26.5	7.4	7.1	0.25	--
21h	28.0	26.5	7.3	7.1	0.26	--

		SS (mg/L)	VSS (mg/L)	BOD (mg/L)			COD (mg/L)		
Date	Time			Total	Dissolved	Particulate	Total	Dissolved	Particulate
1/11/2014	7h	18.6	15.4	7.7	4.8	12.6	27.6	14.2	41.8
	11h	19.7	17.1	21.1	15.0	36.1	60.3	23.7	84.0
	16h	22.3	19	15.9	12.2	28.1	49.7	24.2	74.0
	20h	24.1	21.9	19.1	16.2	35.3	56.1	32.1	88.2
19/11/2014	7h	19.3	13.2	8.0	3.8	11.8	22.9	16.3	39.2
	11h	27.1	18.1	15.0	11.9	26.9	44.2	35.0	79.2
	16h	26.7	12	18.2	3.1	21.3	45.5	21.1	66.6
	20h	36.3	12.3	17.8	12.0	29.8	50.8	34.2	85.0

		NH4 (mg/L)			TN (mg/L)			TP (mg/L)		
Date	Time	Total	Dissolved	Particulate	Total	Dissolved	Particulate	Total	Dissolved	Particulate
1/11/2014	7h	16.77	1.02	17.79	15.96	5.02	20.98	0.52	0.66	1.18
	11h	17.02	0.50	17.52	17.53	2.91	20.44	0.86	1.41	2.27
	16h	21.54	0.49	22.03	19.70	5.11	24.81	1.62	0.35	1.97
	20h	21.67	0.76	22.43	20.39	5.72	26.11	1.37	0.85	2.22
19/11/2014	7h	15.96	1.49	17.45	17.94	0.25	18.19	1.74	0.37	2.11
	11h	17.09	0.17	17.26	19.28	1.63	20.91	1.78	0.23	2.01
	16h	21.04	0.30	21.34	23.69	2.01	25.70	2.43	0.40	2.83
	20h	22.23	2.74	24.97	26.96	0.67	27.63	1.77	0.65	2.42

Appendix I (F1)

ANOVA table – Water consumption in 4 days (Chapter 4)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.53607748	3	2.178692493	0.345579424	0.79241789	2.703594041
Within Groups	580.0105437	92	6.304462431			
Total	586.5466211	95				

ANOVA table – Water consumption on weekdays and weekends (Chapter 4)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.096945805	1	2.0969458	0.33726241	0.56280344	3.94230334
Within Groups	584.4496753	94	6.21754974			
Total	586.5466211	95				

Appendix I (F2)

ANOVA table – Discharge flow rate on dry days in dry season 2015 (Chapter 4)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	7.918	3	2.639	1.542	0.209	2.699
Within Groups	164.369	96	1.712			
Total	172.287	99				

ANOVA table – Discharge flow rate on weekdays and weekends in dry season 2015 (Chapter 4)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	0.116	1	0.116	0.066	0.798	3.938
Within Groups	172.171	98	1.757			
Total	172.287	99				

Appendix II (A)

Head over the V-Notch weir in March 2016 (Chapter 5)

	H (m)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
0:00	0.035	0.032	0.036	0.037	0.037	0.042	0.039	0.042	0.049	0.047	0.043	0.041	0.043	0.041	0.044
0:15	0.033	0.031	0.034	0.035	0.036	0.040	0.038	0.041	0.047	0.046	0.044	0.040	0.042	0.039	0.043
0:30	0.032	0.030	0.033	0.034	0.035	0.039	0.037	0.039	0.046	0.045	0.046	0.039	0.041	0.038	0.041
0:45	0.032	0.029	0.031	0.033	0.034	0.038	0.036	0.038	0.044	0.044	0.047	0.038	0.040	0.037	0.039
1:00	0.031	0.027	0.030	0.033	0.032	0.036	0.035	0.037	0.043	0.043	0.047	0.037	0.039	0.036	0.038
1:15	0.030	0.027	0.029	0.032	0.031	0.035	0.035	0.036	0.042	0.043	0.047	0.036	0.039	0.036	0.037
1:30	0.029	0.026	0.028	0.031	0.030	0.035	0.034	0.036	0.041	0.042	0.046	0.035	0.039	0.035	0.036
1:45	0.028	0.026	0.028	0.031	0.029	0.034	0.034	0.036	0.040	0.042	0.044	0.035	0.038	0.035	0.035
2:00	0.028	0.025	0.027	0.030	0.029	0.034	0.034	0.036	0.039	0.041	0.043	0.034	0.037	0.034	0.033
2:15	0.027	0.025	0.027	0.030	0.028	0.034	0.034	0.036	0.038	0.039	0.041	0.034	0.037	0.034	0.032
2:30	0.026	0.025	0.027	0.029	0.028	0.033	0.033	0.036	0.038	0.038	0.041	0.033	0.036	0.033	0.032
2:45	0.026	0.025	0.026	0.028	0.028	0.033	0.033	0.036	0.037	0.037	0.041	0.033	0.035	0.033	0.031
3:00	0.025	0.024	0.026	0.028	0.027	0.032	0.033	0.035	0.037	0.036	0.041	0.032	0.035	0.033	0.030
3:15	0.024	0.023	0.026	0.027	0.027	0.032	0.034	0.035	0.037	0.035	0.040	0.032	0.034	0.032	0.030
3:30	0.024	0.023	0.025	0.026	0.026	0.031	0.034	0.035	0.037	0.034	0.039	0.032	0.034	0.032	0.029
3:45	0.024	0.022	0.025	0.026	0.026	0.031	0.034	0.034	0.036	0.033	0.038	0.031	0.033	0.032	0.029
4:00	0.023	0.022	0.025	0.027	0.026	0.030	0.035	0.034	0.036	0.033	0.036	0.031	0.033	0.032	0.029
4:15	0.023	0.022	0.024	0.027	0.026	0.030	0.034	0.034	0.035	0.033	0.036	0.031	0.033	0.032	0.029
4:30	0.023	0.022	0.024	0.027	0.025	0.030	0.034	0.034	0.035	0.034	0.035	0.030	0.033	0.032	0.029
4:45	0.023	0.021	0.024	0.027	0.025	0.029	0.034	0.034	0.035	0.035	0.034	0.030	0.032	0.032	0.029
5:00	0.023	0.021	0.024	0.028	0.024	0.029	0.034	0.034	0.034	0.036	0.034	0.030	0.032	0.032	0.029
5:15	0.023	0.021	0.023	0.028	0.024	0.029	0.033	0.034	0.034	0.037	0.034	0.030	0.032	0.032	0.029
5:30	0.023	0.022	0.023	0.028	0.024	0.029	0.033	0.034	0.035	0.038	0.034	0.030	0.032	0.032	0.029
5:45	0.023	0.022	0.023	0.028	0.025	0.028	0.033	0.034	0.036	0.036	0.034	0.030	0.032	0.032	0.029
6:00	0.023	0.022	0.023	0.028	0.024	0.028	0.033	0.034	0.037	0.034	0.035	0.030	0.032	0.032	0.029
6:15	0.023	0.023	0.023	0.029	0.025	0.028	0.033	0.034	0.038	0.035	0.035	0.031	0.032	0.033	0.030
6:30	0.024	0.024	0.025	0.030	0.025	0.029	0.034	0.035	0.038	0.035	0.036	0.031	0.033	0.035	0.032
6:45	0.029	0.025	0.026	0.032	0.028	0.030	0.036	0.038	0.040	0.038	0.038	0.032	0.034	0.037	0.033

	H (m)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
7:00	0.030	0.029	0.028	0.033	0.029	0.033	0.039	0.040	0.041	0.040	0.040	0.034	0.036	0.039	0.034
7:15	0.034	0.032	0.030	0.035	0.032	0.036	0.043	0.043	0.045	0.044	0.042	0.036	0.038	0.041	0.037
7:30	0.045	0.034	0.033	0.038	0.034	0.037	0.046	0.045	0.049	0.046	0.045	0.037	0.039	0.044	0.039
7:45	0.044	0.037	0.035	0.039	0.036	0.039	0.049	0.046	0.051	0.047	0.047	0.040	0.040	0.046	0.041
8:00	0.043	0.041	0.038	0.041	0.038	0.043	0.050	0.049	0.051	0.047	0.048	0.042	0.041	0.047	0.042
8:15	0.042	0.042	0.041	0.045	0.040	0.046	0.053	0.049	0.051	0.047	0.050	0.044	0.045	0.048	0.045
8:30	0.042	0.041	0.041	0.046	0.045	0.046	0.055	0.048	0.052	0.048	0.050	0.046	0.049	0.049	0.046
8:45	0.041	0.040	0.042	0.046	0.047	0.045	0.051	0.049	0.052	0.050	0.051	0.046	0.050	0.049	0.046
9:00	0.040	0.041	0.041	0.046	0.048	0.043	0.048	0.054	0.052	0.051	0.051	0.046	0.050	0.048	0.046
9:15	0.040	0.042	0.040	0.046	0.048	0.043	0.046	0.054	0.051	0.051	0.050	0.047	0.051	0.047	0.048
9:30	0.039	0.043	0.038	0.047	0.049	0.043	0.046	0.053	0.052	0.051	0.048	0.047	0.051	0.046	0.047
9:45	0.038	0.042	0.041	0.048	0.049	0.044	0.046	0.051	0.052	0.050	0.047	0.048	0.050	0.046	0.047
10:00	0.041	0.044	0.044	0.051	0.052	0.046	0.048	0.053	0.055	0.049	0.046	0.049	0.053	0.047	0.051
10:15	0.042	0.042	0.044	0.051	0.052	0.049	0.050	0.053	0.054	0.050	0.046	0.049	0.055	0.048	0.051
10:30	0.043	0.042	0.043	0.049	0.051	0.050	0.050	0.055	0.055	0.051	0.045	0.050	0.055	0.048	0.049
10:45	0.043	0.044	0.041	0.050	0.050	0.052	0.049	0.055	0.057	0.052	0.045	0.055	0.055	0.048	0.049
11:00	0.044	0.048	0.043	0.051	0.050	0.053	0.050	0.055	0.057	0.052	0.047	0.057	0.056	0.050	0.049
11:15	0.042	0.051	0.045	0.052	0.051	0.053	0.052	0.057	0.058	0.053	0.049	0.055	0.058	0.051	0.049
11:30	0.041	0.050	0.045	0.051	0.052	0.053	0.054	0.058	0.058	0.055	0.050	0.053	0.057	0.051	0.050
11:45	0.043	0.050	0.045	0.051	0.052	0.053	0.055	0.058	0.057	0.057	0.051	0.053	0.056	0.050	0.051
12:00	0.044	0.050	0.046	0.049	0.050	0.051	0.055	0.060	0.057	0.056	0.051	0.053	0.056	0.050	0.052
12:15	0.045	0.052	0.048	0.050	0.049	0.050	0.055	0.060	0.057	0.054	0.052	0.053	0.058	0.052	0.052
12:30	0.047	0.051	0.049	0.051	0.048	0.052	0.054	0.060	0.059	0.054	0.057	0.052	0.059	0.053	0.052
12:45	0.046	0.049	0.048	0.051	0.049	0.053	0.052	0.061	0.060	0.053	0.059	0.052	0.059	0.052	0.051
13:00	0.047	0.048	0.047	0.051	0.048	0.053	0.050	0.060	0.061	0.052	0.061	0.053	0.057	0.052	0.048
13:15	0.047	0.046	0.048	0.050	0.048	0.052	0.049	0.058	0.060	0.051	0.060	0.054	0.055	0.050	0.046
13:30	0.046	0.045	0.046	0.051	0.048	0.051	0.048	0.058	0.058	0.050	0.058	0.053	0.054	0.049	0.045
13:45	0.047	0.043	0.045	0.051	0.048	0.051	0.048	0.056	0.057	0.050	0.055	0.052	0.054	0.049	0.045
14:00	0.046	0.042	0.044	0.050	0.046	0.051	0.048	0.055	0.056	0.049	0.053	0.052	0.056	0.048	0.045
14:15	0.046	0.041	0.044	0.050	0.047	0.051	0.048	0.055	0.054	0.049	0.052	0.052	0.055	0.047	0.046
14:30	0.044	0.043	0.045	0.049	0.049	0.051	0.047	0.055	0.052	0.049	0.051	0.052	0.055	0.046	0.047
14:45	0.043	0.043	0.043	0.049	0.050	0.051	0.046	0.054	0.051	0.050	0.049	0.051	0.053	0.046	0.046
15:00	0.043	0.043	-	0.049	0.051	0.051	0.048	0.057	0.052	0.051	0.048	0.051	0.052	0.045	0.045
15:15	0.042	0.042	-	0.050	0.050	0.050	0.049	0.056	0.053	0.053	0.046	0.053	0.051	0.047	0.045
15:30	0.040	0.040	-	0.049	0.049	0.049	0.049	0.056	0.053	0.056	0.048	0.052	0.054	0.048	0.044
15:45	0.039	0.040	-	0.050	0.049	0.049	0.049	0.054	0.054	0.054	0.048	0.052	0.054	0.050	0.045

	H (m)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
16:00	0.046	0.044	-	0.052	0.052	0.048	0.052	0.056	0.056	0.053	0.047	0.054	0.054	0.054	0.050
16:15	0.046	0.043	-	0.049	0.053	0.048	0.051	0.056	0.055	0.051	0.046	0.053	0.054	0.051	0.050
16:30	0.043	0.041	-	0.047	0.052	0.048	0.050	0.055	0.054	0.051	0.047	0.052	0.055	0.048	0.049
16:45	0.042	0.042	-	0.045	0.051	0.047	0.051	0.055	0.054	0.050	0.048	0.051	0.054	0.047	0.050
17:00	0.043	0.042	-	0.046	0.048	0.046	0.051	0.054	0.055	0.051	0.049	0.053	0.054	0.047	0.050
17:15	0.041	0.041	-	0.045	0.048	0.046	0.051	0.054	0.056	0.050	0.049	0.052	0.052	0.046	0.049
17:30	0.040	0.040	-	0.045	0.047	0.047	0.051	0.055	0.057	0.050	0.049	0.051	0.051	0.046	0.048
17:45	0.043	0.041	-	0.045	0.048	0.048	0.050	0.056	0.056	0.050	0.049	0.051	0.051	0.046	0.049
18:00	0.044	0.043	-	0.047	0.048	0.048	0.050	0.058	0.056	0.050	0.050	0.051	0.052	0.047	0.051
18:15	0.045	0.044	0.047	0.049	0.047	0.048	0.051	0.059	0.056	0.050	0.051	0.051	0.052	0.046	0.052
18:30	0.046	0.046	0.046	0.051	0.048	0.049	0.052	0.060	0.057	0.050	0.052	0.052	0.051	0.046	0.053
18:45	0.046	0.044	0.045	0.051	0.049	0.050	0.051	0.061	0.057	0.050	0.054	0.052	0.050	0.046	0.052
19:00	0.044	0.043	0.045	0.049	0.048	0.051	0.051	0.060	0.057	0.051	0.055	0.051	0.051	0.046	0.052
19:15	0.044	0.044	0.046	0.049	0.046	0.050	0.051	0.058	0.057	0.050	0.055	0.056	0.051	0.047	0.051
19:30	0.044	0.045	0.047	0.049	0.046	0.050	0.051	0.058	0.058	0.050	0.054	0.056	0.051	0.047	0.050
19:45	0.044	0.045	0.048	0.048	0.046	0.052	0.050	0.057	0.058	0.050	0.053	0.055	0.050	0.048	0.049
20:00	0.045	0.045	0.047	0.048	0.046	0.052	0.051	0.056	0.057	0.050	0.051	0.053	0.050	0.048	0.050
20:15	0.045	0.043	0.047	0.047	0.046	0.051	0.051	0.054	0.058	0.049	0.051	0.052	0.051	0.047	0.050
20:30	0.044	0.042	0.046	0.047	0.045	0.054	0.050	0.053	0.057	0.049	0.050	0.052	0.053	0.047	0.049
20:45	0.043	0.042	0.046	0.046	0.044	0.055	0.049	0.053	0.056	0.050	0.050	0.051	0.053	0.047	0.048
21:00	0.043	0.042	0.045	0.045	0.043	0.054	0.048	0.055	0.055	0.051	0.049	0.050	0.052	0.048	0.046
21:15	0.042	0.041	0.045	0.044	0.043	0.052	0.047	0.057	0.055	0.051	0.048	0.048	0.050	0.048	0.045
21:30	0.042	0.042	0.044	0.043	0.044	0.051	0.048	0.058	0.056	0.050	0.048	0.048	0.049	0.049	0.045
21:45	0.042	0.041	0.043	0.043	0.047	0.050	0.049	0.057	0.056	0.048	0.048	0.048	0.049	0.047	0.046
22:00	0.041	0.042	0.042	0.042	0.047	0.050	0.049	0.056	0.055	0.047	0.047	0.049	0.049	0.047	0.047
22:15	0.041	0.043	0.042	0.042	0.046	0.051	0.049	0.056	0.054	0.045	0.047	0.048	0.049	0.047	0.047
22:30	0.040	0.041	0.041	0.041	0.045	0.050	0.049	0.056	0.054	0.045	0.046	0.048	0.049	0.046	0.046
22:45	0.039	0.041	0.042	0.042	0.045	0.049	0.050	0.054	0.054	0.045	0.047	0.047	0.051	0.046	0.048
23:00	0.040	0.043	0.043	0.042	0.046	0.048	0.049	0.055	0.055	0.047	0.046	0.049	0.050	0.046	0.048
23:15	0.039	0.042	0.043	0.041	0.047	0.047	0.048	0.055	0.055	0.047	0.045	0.049	0.048	0.045	0.047
23:30	0.037	0.039	0.041	0.039	0.046	0.044	0.045	0.054	0.052	0.045	0.044	0.048	0.046	0.044	0.045
23:45	0.034	0.038	0.039	0.038	0.044	0.041	0.043	0.052	0.050	0.044	0.042	0.046	0.043	0.044	0.044

	H (m)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
0:00	0.043	0.044	0.044	0.045	0.048	0.038	0.044	0.043	0.043	0.041	-	0.042	0.032	0.033
0:15	0.041	0.042	0.042	0.044	0.047	0.037	0.042	0.043	0.042	0.043	-	0.040	0.031	0.032
0:30	0.040	0.041	0.040	0.042	0.045	0.037	0.041	0.042	0.040	0.043	-	0.039	0.030	0.030
0:45	0.039	0.040	0.039	0.041	0.043	0.036	0.039	0.041	0.039	0.044	-	0.038	0.029	0.028
1:00	0.039	0.039	0.038	0.040	0.042	0.036	0.038	0.039	0.037	0.043	-	0.037	0.028	0.027
1:15	0.038	0.039	0.037	0.039	0.041	0.035	0.037	0.038	0.036	0.044	-	0.036	0.028	0.026
1:30	0.036	0.039	0.036	0.038	0.040	0.033	0.036	0.037	0.035	0.045	-	0.035	0.028	0.024
1:45	0.035	0.038	0.035	0.037	0.038	0.033	0.035	0.037	0.035	0.047	-	0.035	0.028	0.023
2:00	0.033	0.037	0.034	0.036	0.037	0.031	0.035	0.036	0.034	0.051	-	0.035	0.029	0.022
2:15	0.032	0.036	0.033	0.035	0.036	0.031	0.033	0.036	0.033	0.054	-	0.034	0.029	0.020
2:30	0.032	0.036	0.033	0.035	0.035	0.030	0.032	0.035	0.032	0.055	0.058	0.034	0.029	0.020
2:45	0.031	0.036	0.032	0.034	0.034	0.029	0.032	0.034	0.031	0.054	0.050	0.034	0.029	0.019
3:00	0.030	0.035	0.031	0.033	0.033	0.029	0.031	0.033	0.030	0.052	0.048	0.034	0.029	0.019
3:15	0.030	0.035	0.031	0.033	0.033	0.028	0.031	0.033	0.030	0.050	0.044	0.034	0.029	0.019
3:30	0.029	0.034	0.030	0.032	0.032	0.028	0.030	0.032	0.029	0.048	0.044	0.034	0.029	0.019
3:45	0.029	0.034	0.030	0.032	0.031	0.027	0.030	0.031	0.029	0.046	0.043	0.034	0.029	0.018
4:00	0.029	0.034	0.030	0.031	0.031	0.027	0.029	0.031	0.029	0.048	0.043	0.034	0.029	0.018
4:15	0.029	0.034	0.029	0.031	0.031	0.027	0.029	0.031	0.028	0.057	0.042	0.034	0.029	0.018
4:30	0.028	0.033	0.029	0.031	0.030	0.027	0.029	0.030	0.028	0.063	0.041	0.035	0.028	0.017
4:45	0.028	0.033	0.029	0.031	0.030	0.027	0.029	0.030	0.028	0.065	0.039	0.035	0.027	0.017
5:00	0.028	0.034	0.029	0.030	0.030	0.027	0.028	0.030	0.028	0.063	0.037	0.035	0.027	0.017
5:15	0.028	0.034	0.029	0.031	0.029	0.027	0.029	0.030	0.028	0.059	0.035	0.035	0.027	0.017
5:30	0.028	0.034	0.029	0.030	0.029	0.027	0.029	0.030	0.028	0.055	0.034	0.035	0.026	0.018
5:45	0.028	0.034	0.029	0.031	0.030	0.027	0.029	0.030	0.029	0.052	0.036	0.036	0.027	0.018
6:00	0.029	0.033	0.030	0.031	0.030	0.027	0.029	0.030	0.029	0.049	0.038	0.036	0.027	0.019
6:15	0.029	0.033	0.030	0.031	0.030	0.029	0.030	0.031	0.031	0.046	0.040	0.036	0.028	0.022
6:30	0.031	0.033	0.032	0.032	0.032	0.031	0.031	0.032	0.032	0.044	0.041	0.039	0.030	0.023
6:45	0.033	0.035	0.035	0.033	0.033	0.037	0.034	0.034	0.035	0.043	0.041	0.041	0.033	0.026

	H (m)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
7:00	0.035	0.037	0.038	0.035	0.034	0.045	0.036	0.037	0.039	0.043	0.042	0.042	0.034	0.027
7:15	0.039	0.039	0.040	0.038	0.036	0.049	0.037	0.041	0.042	0.042	0.044	0.044	0.036	0.029
7:30	0.040	0.040	0.043	0.039	0.039	0.050	0.040	0.043	0.044	0.042	0.045	0.045	0.037	0.031
7:45	0.042	0.043	0.045	0.042	0.041	0.050	0.044	0.046	0.043	0.042	0.045	0.045	0.040	0.033
8:00	0.044	0.045	0.047	0.048	0.045	0.050	0.046	0.047	0.042	0.041	0.047	0.048	0.042	0.034
8:15	0.045	0.048	0.048	0.051	0.049	0.049	0.047	0.048	0.043	0.041	0.049	0.049	0.044	0.036
8:30	0.047	0.049	0.049	0.053	0.052	0.048	0.046	0.048	0.045	0.042	0.049	0.048	0.043	0.038
8:45	0.048	0.050	0.049	0.054	0.055	0.048	0.045	0.047	0.046	0.044	0.047	0.049	0.042	0.042
9:00	0.049	0.050	0.048	0.055	0.059	0.047	0.045	0.047	0.045	0.045	0.048	0.050	0.040	0.041
9:15	0.049	0.050	0.048	0.056	0.057	0.046	0.045	0.048	0.046	0.046	0.049	0.049	0.040	0.040
9:30	0.050	0.050	0.048	0.056	0.055	0.046	0.044	0.048	0.045	0.046	0.048	0.047	0.041	0.037
9:45	0.049	0.050	0.048	0.055	0.052	0.046	0.043	0.046	0.045	0.046	0.047	0.046	0.042	0.035
10:00	0.049	0.051	0.050	0.056	0.052	0.048	0.043	0.045	0.045	0.046	0.048	0.049	0.043	0.036
10:15	0.048	0.052	0.051	0.056	0.050	0.050	0.043	0.045	0.045	0.046	0.047	0.050	0.043	0.037
10:30	0.047	0.054	0.052	0.055	0.049	0.051	0.043	0.045	0.046	0.046	0.047	0.049	0.041	0.038
10:45	0.047	0.054	0.052	0.056	0.049	0.052	0.044	0.046	0.046	0.046	0.049	0.049	0.040	0.043
11:00	0.047	0.054	0.053	0.058	0.050	0.053	0.045	0.046	0.047	0.046	0.049	0.049	0.042	0.052
11:15	0.048	0.054	0.056	0.058	0.053	0.053	0.047	0.048	0.047	0.048	0.050	0.050	0.044	0.048
11:30	0.050	0.055	0.056	0.057	0.054	0.053	0.048	0.053	0.047	0.047	0.050	0.050	0.046	0.046
11:45	0.051	0.055	0.055	0.056	0.055	0.054	0.049	0.055	0.047	0.047	0.051	0.051	0.045	0.046
12:00	0.053	0.056	0.054	0.058	0.054	0.054	0.050	0.055	0.047	0.047	0.052	0.050	0.045	0.045
12:15	0.053	0.057	0.054	0.059	0.052	0.053	0.051	0.055	0.048	0.047	0.051	0.051	0.043	0.043
12:30	0.054	0.058	0.055	0.061	0.052	0.055	0.052	0.055	0.049	0.048	0.051	0.052	0.043	0.043
12:45	0.055	0.057	0.055	0.061	0.053	0.054	0.054	0.055	0.049	0.049	0.051	0.053	0.043	0.043
13:00	0.054	0.056	0.055	0.062	0.053	0.054	0.053	0.053	0.048	0.051	0.053	0.051	0.042	0.042
13:15	0.053	0.054	0.055	0.061	0.053	0.054	0.051	0.053	0.049	0.052	0.054	0.048	0.042	0.041
13:30	0.052	0.053	0.054	0.061	0.052	0.054	0.049	0.052	0.048	0.053	0.053	0.046	0.041	0.040
13:45	0.051	0.051	0.054	0.062	0.053	0.053	0.048	0.051	0.050	0.052	0.052	0.044	0.042	0.039
14:00	0.050	0.050	0.055	0.061	0.054	0.051	0.047	0.051	0.049	0.051	0.051	0.042	0.041	0.038
14:15	0.051	0.052	0.053	0.060	0.053	0.050	0.047	0.051	0.047	0.049	0.053	0.040	0.039	0.038
14:30	0.050	0.052	0.052	0.062	0.051	0.050	0.046	0.051	0.046	0.047	0.052	0.040	0.038	0.040
14:45	0.049	0.051	0.051	0.060	0.049	0.049	0.046	0.052	0.045	0.045	0.049	0.041	0.040	0.039
15:00	0.049	0.052	0.051	0.061	0.049	0.050	0.046	0.051	0.045	0.043	0.049	0.041	0.042	0.039
15:15	0.050	0.052	0.051	0.060	0.048	0.050	0.047	0.050	0.045	0.042	0.049	0.042	0.042	0.040
15:30	0.052	0.051	0.050	0.058	0.049	0.050	0.046	0.049	0.045	0.041	0.049	0.044	0.041	0.039
15:45	0.053	0.052	0.048	0.059	0.050	0.050	0.045	0.049	0.044	0.041	0.050	0.045	0.042	0.038

	H (m)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
16:00	0.055	0.051	0.051	0.060	0.050	0.054	0.045	0.050	0.043	0.041	0.052	0.046	0.044	0.037
16:15	0.055	0.050	0.051	0.059	0.051	0.052	0.045	0.050	0.043	0.041	0.050	0.044	0.042	0.038
16:30	0.054	0.050	0.051	0.058	0.050	0.051	0.045	0.049	0.043	0.042	0.049	0.042	0.041	0.038
16:45	0.053	0.049	0.051	0.059	0.050	0.051	0.047	0.049	0.043	0.044	0.051	0.041	0.042	0.037
17:00	0.054	0.049	0.051	0.061	0.050	0.051	0.048	0.049	0.044	0.045	0.052	0.041	0.042	0.038
17:15	0.053	0.048	0.052	0.062	0.050	0.050	0.049	0.049	0.044	0.048	0.052	0.040	0.042	0.041
17:30	0.053	0.048	0.053	0.060	0.050	0.051	0.049	0.050	0.046	0.051	0.051	0.040	0.042	0.042
17:45	0.056	0.049	0.055	0.059	0.050	0.052	0.050	0.050	0.048	0.058	0.050	0.042	0.042	0.043
18:00	0.059	0.050	0.056	0.059	0.049	0.054	0.050	0.052	0.048	0.065	0.049	0.044	0.041	0.045
18:15	0.058	0.051	0.056	0.058	0.050	0.054	0.050	0.052	0.049	0.067	0.050	0.045	0.041	0.047
18:30	0.057	0.052	0.055	0.057	0.051	0.054	0.050	0.052	0.052	0.066	0.051	0.045	0.040	0.049
18:45	0.056	0.052	0.056	0.057	0.053	0.054	0.050	0.051	0.053	0.064	0.050	0.044	0.041	0.049
19:00	0.055	0.052	0.057	0.057	0.054	0.054	0.051	0.052	0.054	0.064	0.050	0.045	0.041	0.050
19:15	0.053	0.053	0.055	0.057	0.054	0.054	0.052	0.052	0.055	0.063	0.052	0.044	0.041	0.054
19:30	0.053	0.053	0.055	0.058	0.054	0.054	0.052	0.053	0.055	0.063	0.052	0.043	0.041	0.055
19:45	0.052	0.052	0.055	0.057	0.054	0.053	0.054	0.052	0.055	0.065	0.053	0.042	0.040	0.050
20:00	0.052	0.051	0.056	0.056	0.054	0.052	0.053	0.053	0.054	0.066	0.052	0.042	0.040	0.047
20:15	0.052	0.051	0.055	0.056	0.054	0.050	0.053	0.053	0.055	0.066	0.051	0.041	0.040	0.044
20:30	0.053	0.052	0.056	0.056	0.054	0.050	0.053	0.053	0.056	0.065	0.050	0.040	0.041	0.041
20:45	0.052	0.051	0.056	0.055	0.054	0.051	0.052	0.054	0.056	0.062	0.050	0.039	0.040	0.040
21:00	0.052	0.050	0.055	0.054	0.054	0.051	0.051	0.054	0.056	0.059	0.050	0.038	0.039	0.038
21:15	0.053	0.049	0.054	0.053	0.053	0.051	0.049	0.053	0.057	0.057	0.049	0.038	0.038	0.038
21:30	0.054	0.049	0.053	0.053	0.054	0.052	0.048	0.053	0.058	0.057	0.049	0.038	0.037	0.038
21:45	0.056	0.049	0.053	0.056	0.053	0.051	0.049	0.052	0.061	0.055	0.050	0.039	0.036	0.038
22:00	0.055	0.050	0.053	0.055	0.054	0.050	0.049	0.053	0.063	0.053	0.052	0.040	0.035	0.038
22:15	0.052	0.050	0.053	0.053	0.053	0.049	0.049	0.053	0.064	0.051	0.051	0.040	0.036	0.039
22:30	0.051	0.051	0.051	0.052	0.053	0.047	0.049	0.053	0.066	0.048	0.050	0.040	0.037	0.040
22:45	0.051	0.053	0.050	0.052	0.051	0.047	0.050	0.054	0.065	0.046	0.049	0.040	0.040	0.041
23:00	0.051	0.051	0.050	0.052	0.049	0.048	0.049	0.053	0.063	0.043	0.048	0.038	0.038	0.040
23:15	0.049	0.049	0.050	0.051	0.046	0.048	0.048	0.050	0.061	0.041	0.046	0.037	0.037	0.038
23:30	0.047	0.047	0.048	0.050	0.043	0.047	0.046	0.047	0.060	-	0.045	0.035	0.035	0.036
23:45	0.046	0.046	0.046	0.050	0.041	0.046	0.044	0.045	0.059	-	0.044	0.033	0.034	0.036

Appendix II (B)

Flow rate in March 2016 (Chapter 5)

	Flowrate (m3/h)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
0:00	1.33	1.04	1.40	1.30	1.34	1.81	1.51	1.85	2.66	2.41	2.00	1.74	1.92	1.70	2.10
0:15	1.13	0.97	1.22	1.14	1.25	1.61	1.43	1.72	2.43	2.32	2.18	1.63	1.85	1.51	1.94
0:30	1.07	0.89	1.13	1.08	1.16	1.53	1.34	1.51	2.30	2.20	2.42	1.53	1.74	1.43	1.70
0:45	1.07	0.80	0.95	1.02	1.06	1.41	1.25	1.43	2.06	2.08	2.51	1.43	1.63	1.34	1.51
1:00	0.97	0.67	0.89	1.02	0.91	1.23	1.18	1.34	1.96	1.98	2.49	1.34	1.55	1.27	1.43
1:15	0.89	0.68	0.81	0.92	0.85	1.18	1.18	1.27	1.85	1.98	2.47	1.25	1.57	1.27	1.34
1:30	0.81	0.62	0.75	0.87	0.78	1.18	1.10	1.29	1.74	1.87	2.30	1.18	1.55	1.18	1.25
1:45	0.75	0.62	0.75	0.87	0.73	1.10	1.12	1.29	1.63	1.87	2.06	1.18	1.43	1.18	1.14
2:00	0.75	0.56	0.68	0.80	0.73	1.12	1.12	1.29	1.53	1.72	1.94	1.10	1.36	1.10	0.98
2:15	0.67	0.57	0.70	0.80	0.67	1.10	1.10	1.29	1.45	1.51	1.74	1.10	1.36	1.10	0.94
2:30	0.62	0.57	0.68	0.72	0.69	1.02	1.02	1.29	1.45	1.43	1.78	1.02	1.25	1.02	0.94
2:45	0.62	0.56	0.62	0.67	0.67	1.02	1.04	1.27	1.36	1.34	1.78	1.02	1.18	1.04	0.85
3:00	0.55	0.49	0.63	0.67	0.61	0.94	1.06	1.18	1.38	1.25	1.76	0.94	1.18	1.02	0.80
3:15	0.50	0.45	0.62	0.59	0.61	0.94	1.14	1.20	1.38	1.16	1.63	0.96	1.10	0.94	0.80
3:30	0.52	0.45	0.56	0.56	0.56	0.87	1.12	1.18	1.36	1.08	1.53	0.94	1.10	0.96	0.73
3:45	0.50	0.40	0.57	0.59	0.57	0.87	1.14	1.10	1.27	1.02	1.41	0.87	1.02	0.96	0.75
4:00	0.45	0.41	0.56	0.65	0.57	0.80	1.20	1.12	1.27	1.04	1.25	0.89	1.04	0.96	0.75
4:15	0.46	0.41	0.50	0.63	0.56	0.82	1.10	1.12	1.18	1.06	1.27	0.87	1.04	0.96	0.75
4:30	0.46	0.40	0.52	0.63	0.50	0.80	1.12	1.12	1.20	1.15	1.16	0.80	1.02	0.96	0.75
4:45	0.46	0.35	0.52	0.65	0.50	0.73	1.12	1.12	1.18	1.24	1.10	0.82	0.94	0.96	0.75
5:00	0.46	0.37	0.50	0.71	0.45	0.75	1.10	1.12	1.10	1.32	1.12	0.82	0.96	0.96	0.75
5:15	0.46	0.38	0.45	0.69	0.47	0.75	1.02	1.12	1.14	1.41	1.12	0.82	0.96	0.96	0.75
5:30	0.46	0.43	0.46	0.69	0.49	0.73	1.04	1.12	1.24	1.45	1.12	0.82	0.96	0.96	0.75
5:45	0.46	0.41	0.46	0.69	0.52	0.67	1.04	1.12	1.32	1.21	1.14	0.82	0.96	0.96	0.75
6:00	0.46	0.43	0.46	0.71	0.47	0.69	1.04	1.12	1.41	1.10	1.22	0.84	0.96	0.98	0.77
6:15	0.48	0.49	0.49	0.79	0.54	0.71	1.06	1.14	1.49	1.22	1.22	0.91	0.98	1.09	0.87
6:30	0.59	0.54	0.61	0.87	0.57	0.79	1.17	1.27	1.51	1.26	1.34	0.91	1.07	1.27	1.02
6:45	0.92	0.64	0.67	1.02	0.76	0.89	1.38	1.57	1.73	1.57	1.55	1.02	1.17	1.45	1.07

	Flowrate (m3/h)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
7:00	0.98	0.93	0.82	1.09	0.83	1.15	1.70	1.77	1.87	1.79	1.75	1.19	1.36	1.65	1.19
7:15	1.47	1.15	0.98	1.29	1.05	1.36	2.14	2.10	2.40	2.23	1.98	1.34	1.53	1.87	1.47
7:30	2.73	1.33	1.24	1.55	1.19	1.43	2.48	2.30	2.88	2.42	2.34	1.45	1.61	2.21	1.65
7:45	2.42	1.67	1.43	1.63	1.36	1.68	2.84	2.44	3.09	2.51	2.55	1.77	1.71	2.42	1.83
8:00	2.28	2.11	1.76	1.89	1.55	2.14	2.99	2.82	3.05	2.49	2.69	1.96	1.87	2.53	1.96
8:15	2.16	2.17	2.08	2.34	1.81	2.42	3.46	2.74	3.07	2.51	2.95	2.19	2.40	2.67	2.32
8:30	2.16	2.01	2.05	2.38	2.37	2.34	3.64	2.63	3.22	2.69	2.93	2.40	2.86	2.78	2.38
8:45	2.01	1.91	2.17	2.36	2.55	2.18	2.91	2.89	3.20	2.97	3.07	2.36	2.93	2.74	2.36
9:00	1.90	2.07	2.01	2.36	2.65	1.96	2.53	3.62	3.18	3.07	3.03	2.38	2.93	2.59	2.40
9:15	1.90	2.20	1.87	2.38	2.65	2.00	2.32	3.50	3.05	3.05	2.85	2.51	3.07	2.45	2.65
9:30	1.77	2.31	1.69	2.53	2.78	2.02	2.36	3.30	3.22	3.03	2.57	2.51	3.03	2.34	2.47
9:45	1.71	2.19	2.13	2.71	2.82	2.18	2.40	3.05	3.26	2.87	2.45	2.67	2.95	2.38	2.57
10:00	2.10	2.45	2.49	3.11	3.26	2.46	2.71	3.40	3.72	2.76	2.34	2.78	3.46	2.53	3.13
10:15	2.20	2.14	2.43	3.01	3.18	2.84	2.95	3.40	3.52	2.95	2.34	2.78	3.72	2.65	3.01
10:30	2.32	2.20	2.26	2.74	3.01	2.97	2.89	3.72	3.74	3.09	2.22	3.03	3.68	2.63	2.72
10:45	2.32	2.54	2.04	2.95	2.89	3.26	2.76	3.68	4.06	3.22	2.28	3.83	3.70	2.67	2.76
11:00	2.43	3.16	2.36	3.09	2.93	3.38	2.97	3.72	4.04	3.22	2.57	4.02	3.91	2.97	2.76
11:15	2.13	3.60	2.62	3.20	3.09	3.36	3.28	4.08	4.22	3.42	2.82	3.60	4.22	3.07	2.78
11:30	2.05	3.38	2.59	3.03	3.22	3.36	3.58	4.22	4.18	3.76	2.95	3.32	3.98	3.03	2.95
11:45	2.35	3.40	2.61	3.01	3.16	3.32	3.70	4.24	4.00	4.04	3.07	3.36	3.83	2.89	3.09
12:00	2.48	3.43	2.79	2.74	2.84	2.99	3.68	4.61	4.02	3.79	3.07	3.36	3.89	2.95	3.22
12:15	2.64	3.77	3.10	2.95	2.72	2.93	3.66	4.57	4.06	3.48	3.33	3.34	4.26	3.26	3.20
12:30	2.91	3.53	3.22	3.07	2.63	3.26	3.45	4.59	4.44	3.50	4.17	3.18	4.40	3.36	3.18
12:45	2.74	3.18	3.03	3.05	2.76	3.38	3.12	4.76	4.61	3.32	4.47	3.22	4.34	3.18	2.97
13:00	2.91	3.01	2.90	3.03	2.61	3.34	2.84	4.50	4.76	3.16	4.78	3.40	3.94	3.16	2.53
13:15	2.88	2.70	3.04	2.91	2.63	3.16	2.72	4.16	4.50	3.01	4.50	3.52	3.62	2.84	2.30
13:30	2.74	2.55	2.70	3.07	2.63	3.03	2.61	4.16	4.14	2.89	4.09	3.32	3.50	2.74	2.22
13:45	2.90	2.26	2.56	3.03	2.59	3.05	2.63	3.79	3.98	2.89	3.58	3.18	3.56	2.74	2.24
14:00	2.73	2.14	2.43	2.89	2.34	3.05	2.63	3.66	3.79	2.74	3.30	3.20	3.87	2.59	2.26
14:15	2.71	2.05	2.46	2.89	2.55	3.05	2.61	3.68	3.43	2.76	3.16	3.20	3.66	2.45	2.40
14:30	2.40	2.33	2.58	2.74	2.82	3.05	2.45	3.66	3.14	2.78	2.99	3.18	3.64	2.34	2.49
14:45	2.29	2.31	2.29	2.76	2.95	3.05	2.38	3.56	3.05	2.95	2.70	3.03	3.30	2.34	2.32
15:00	2.29	2.29	-	2.78	3.05	3.03	2.69	4.06	3.24	3.11	2.57	3.09	3.16	2.26	2.22
15:15	2.13	2.13	-	2.91	2.87	2.87	2.78	3.83	3.38	3.46	2.36	3.38	3.09	2.55	2.22
15:30	1.87	1.89	-	2.76	2.74	2.74	2.76	3.81	3.38	3.87	2.67	3.18	3.58	2.69	2.12
15:45	1.88	1.97	-	2.97	2.82	2.74	2.82	3.52	3.58	3.45	2.61	3.24	3.52	3.03	2.36

	Flowrate (m3/h)														
Time	**1 March**	**2 March**	**3 March**	**4 March**	**5 March**	**6 March**	**7 March**	**8 March**	**9 March**	**10 March**	**11 March**	**12 March**	**13 March**	**14 March**	**15 March**
16:00	2.84	2.49	-	3.18	3.28	2.61	3.24	3.89	3.87	3.30	2.45	3.54	3.52	3.54	3.01
16:15	2.70	2.26	-	2.66	3.36	2.63	3.01	3.83	3.64	3.01	2.36	3.32	3.54	2.93	2.89
16:30	2.25	2.03	-	2.41	3.16	2.61	2.91	3.66	3.50	3.03	2.53	3.16	3.68	2.55	2.76
16:45	2.17	2.18	-	2.22	2.97	2.45	3.07	3.66	3.54	2.91	2.67	3.07	3.50	2.47	2.93
17:00	2.29	2.16	-	2.36	2.57	2.34	3.05	3.50	3.72	3.05	2.78	3.38	3.48	2.47	2.89
17:15	2.00	2.01	-	2.22	2.61	2.38	3.05	3.54	3.89	2.89	2.76	3.16	3.14	2.34	2.72
17:30	1.94	1.91	-	2.24	2.49	2.53	3.03	3.72	4.02	2.91	2.76	3.03	3.03	2.36	2.63
17:45	2.36	2.08	-	2.28	2.65	2.65	2.89	3.91	3.83	2.91	2.78	3.05	3.07	2.38	2.82
18:00	2.48	2.35	-	2.57	2.61	2.63	2.93	4.26	3.85	2.91	2.95	3.05	3.22	2.49	3.11
18:15	2.62	2.49	2.88	2.84	2.49	2.65	3.09	4.42	3.87	2.91	3.09	3.07	3.18	2.34	3.24
18:30	2.76	2.74	2.70	3.09	2.67	2.80	3.20	4.61	4.04	2.91	3.26	3.22	3.01	2.36	3.36
18:45	2.71	2.40	2.57	3.01	2.76	2.95	3.03	4.76	4.02	2.93	3.58	3.18	2.91	2.36	3.18
19:00	2.42	2.31	2.61	2.72	2.57	3.05	3.05	4.50	4.02	3.05	3.70	3.14	3.07	2.38	3.18
19:15	2.45	2.48	2.78	2.76	2.32	2.89	3.05	4.16	4.04	2.89	3.66	3.95	3.05	2.51	3.01
19:30	2.45	2.61	2.94	2.74	2.36	2.95	3.03	4.18	4.22	2.91	3.48	3.83	3.03	2.51	2.87
19:45	2.46	2.59	3.06	2.61	2.36	3.24	2.91	3.98	4.18	2.91	3.30	3.62	2.89	2.65	2.76
20:00	2.61	2.56	2.88	2.61	2.36	3.18	3.07	3.79	4.02	2.89	3.01	3.30	2.93	2.61	2.93
20:15	2.58	2.26	2.88	2.47	2.34	3.09	3.03	3.45	4.20	2.74	3.03	3.18	3.11	2.47	2.89
20:30	2.42	2.16	2.72	2.47	2.20	3.60	2.87	3.34	3.98	2.78	2.89	3.18	3.40	2.49	2.72
20:45	2.29	2.17	2.72	2.32	2.08	3.68	2.72	3.40	3.81	2.95	2.89	3.01	3.34	2.51	2.57
21:00	2.29	2.16	2.57	2.20	1.98	3.45	2.59	3.76	3.66	3.07	2.72	2.85	3.14	2.65	2.30
21:15	2.16	2.04	2.57	2.08	2.02	3.14	2.49	4.08	3.70	3.03	2.61	2.59	2.84	2.65	2.22
21:30	2.17	2.17	2.41	1.98	2.20	3.01	2.67	4.20	3.87	2.85	2.63	2.63	2.74	2.74	2.26
21:45	2.16	2.04	2.27	1.98	2.55	2.89	2.78	3.98	3.83	2.57	2.61	2.65	2.76	2.45	2.40
22:00	2.03	2.20	2.15	1.87	2.47	2.93	2.76	3.83	3.64	2.43	2.47	2.76	2.76	2.49	2.51
22:15	2.03	2.29	2.15	1.87	2.32	3.05	2.76	3.85	3.50	2.20	2.47	2.61	2.76	2.47	2.47
22:30	1.89	2.01	2.04	1.78	2.22	2.87	2.78	3.81	3.52	2.24	2.36	2.61	2.80	2.34	2.38
22:45	1.79	2.07	2.21	1.91	2.26	2.72	2.91	3.50	3.54	2.28	2.49	2.51	3.07	2.36	2.67
23:00	1.91	2.32	2.33	1.87	2.40	2.59	2.72	3.70	3.70	2.53	2.32	2.80	2.85	2.34	2.61
23:15	1.75	2.11	2.27	1.72	2.49	2.41	2.55	3.66	3.62	2.45	2.20	2.74	2.55	2.20	2.43
23:30	1.50	1.74	1.96	1.51	2.30	2.00	2.14	3.45	3.10	2.18	2.06	2.57	2.26	2.10	2.18
23:45	1.19	1.64	1.72	1.43	2.04	1.68	1.94	3.10	2.80	2.08	1.83	2.26	1.90	2.12	2.08

	Flowrate (m3/h)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
0:00	1.94	2.04	2.04	2.20	2.57	1.39	2.04	1.98	1.94	1.85	-	1.81	0.92	1.00
0:15	1.72	1.83	1.81	2.06	2.43	1.36	1.83	1.98	1.83	2.04	-	1.61	0.85	0.91
0:30	1.63	1.74	1.61	1.83	2.16	1.36	1.72	1.85	1.61	2.02	-	1.53	0.78	0.75
0:45	1.55	1.63	1.53	1.74	1.94	1.27	1.51	1.72	1.51	2.12	-	1.43	0.72	0.64
1:00	1.55	1.55	1.43	1.63	1.85	1.27	1.43	1.51	1.32	2.00	-	1.34	0.67	0.59
1:15	1.41	1.57	1.34	1.53	1.74	1.14	1.34	1.43	1.25	2.16	-	1.25	0.69	0.52
1:30	1.23	1.55	1.25	1.43	1.61	1.00	1.25	1.36	1.18	2.30	-	1.18	0.69	0.42
1:45	1.14	1.43	1.16	1.34	1.41	1.00	1.18	1.36	1.18	2.61	-	1.20	0.71	0.39
2:00	0.98	1.34	1.08	1.25	1.34	0.85	1.16	1.27	1.08	3.19	-	1.18	0.77	0.33
2:15	0.94	1.27	1.02	1.18	1.25	0.87	0.98	1.27	1.00	3.60	-	1.10	0.75	0.27
2:30	0.94	1.29	1.02	1.18	1.16	0.78	0.94	1.16	0.92	3.68	3.82	1.12	0.75	0.28
2:45	0.85	1.27	0.92	1.08	1.08	0.73	0.94	1.08	0.85	3.45	2.70	1.12	0.75	0.25
3:00	0.80	1.18	0.87	1.02	1.02	0.73	0.87	1.02	0.80	3.12	2.51	1.12	0.75	0.26
3:15	0.80	1.18	0.87	1.02	1.02	0.67	0.87	1.02	0.80	2.82	2.04	1.12	0.75	0.26
3:30	0.73	1.10	0.80	0.94	0.92	0.67	0.80	0.92	0.73	2.55	2.10	1.12	0.75	0.25
3:45	0.75	1.12	0.82	0.94	0.87	0.61	0.80	0.87	0.75	2.36	1.98	1.12	0.75	0.21
4:00	0.75	1.12	0.80	0.87	0.89	0.63	0.73	0.89	0.73	2.85	1.98	1.12	0.75	0.23
4:15	0.73	1.10	0.73	0.89	0.87	0.63	0.75	0.87	0.67	4.34	1.85	1.14	0.73	0.21
4:30	0.67	1.02	0.75	0.89	0.80	0.63	0.75	0.80	0.69	5.33	1.72	1.22	0.65	0.18
4:45	0.69	1.06	0.75	0.87	0.82	0.63	0.73	0.82	0.69	5.57	1.49	1.20	0.61	0.20
5:00	0.69	1.14	0.75	0.82	0.80	0.63	0.69	0.82	0.69	5.03	1.30	1.20	0.63	0.20
5:15	0.69	1.12	0.75	0.89	0.73	0.63	0.77	0.82	0.69	4.21	1.14	1.20	0.61	0.22
5:30	0.69	1.12	0.75	0.82	0.77	0.63	0.75	0.82	0.71	3.53	1.14	1.22	0.57	0.25
5:45	0.71	1.10	0.77	0.91	0.84	0.63	0.75	0.82	0.77	3.08	1.36	1.31	0.65	0.25
6:00	0.77	1.02	0.84	0.89	0.82	0.67	0.77	0.84	0.79	2.64	1.55	1.29	0.65	0.33
6:15	0.79	1.04	0.86	0.91	0.86	0.82	0.85	0.92	0.94	2.26	1.73	1.34	0.74	0.45
6:30	0.96	1.07	1.05	1.00	1.02	1.04	0.96	1.02	1.03	2.06	1.80	1.66	0.91	0.49
6:45	1.11	1.27	1.31	1.09	1.07	1.64	1.21	1.21	1.33	1.98	1.80	1.83	1.11	0.64

	Flowrate (m3/h)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
7:00	1.31	1.45	1.57	1.29	1.17	2.47	1.34	1.51	1.70	1.98	1.94	1.94	1.17	0.68
7:15	1.66	1.63	1.77	1.55	1.38	2.86	1.45	1.89	1.98	1.87	2.18	2.18	1.34	0.82
7:30	1.73	1.75	2.10	1.65	1.66	2.93	1.81	2.10	2.14	1.89	2.26	2.26	1.45	0.96
7:45	1.96	2.10	2.32	2.06	1.89	2.91	2.23	2.44	1.96	1.87	2.28	2.30	1.77	1.09
8:00	2.18	2.34	2.55	2.81	2.40	2.89	2.42	2.53	1.89	1.76	2.57	2.71	1.96	1.17
8:15	2.30	2.71	2.67	3.15	2.90	2.72	2.49	2.65	2.06	1.80	2.80	2.76	2.14	1.36
8:30	2.55	2.80	2.78	3.42	3.33	2.61	2.32	2.61	2.30	1.94	2.72	2.63	1.96	1.59
8:45	2.67	2.93	2.74	3.56	3.83	2.61	2.22	2.47	2.36	2.18	2.47	2.80	1.83	1.94
9:00	2.78	2.91	2.61	3.72	4.42	2.45	2.24	2.51	2.24	2.28	2.67	2.91	1.63	1.74
9:15	2.78	2.91	2.63	3.87	3.94	2.34	2.22	2.65	2.36	2.38	2.76	2.70	1.69	1.59
9:30	2.91	2.91	2.63	3.83	3.58	2.36	2.08	2.59	2.22	2.36	2.59	2.43	1.82	1.28
9:45	2.74	2.93	2.67	3.68	3.14	2.40	1.98	2.30	2.24	2.36	2.49	2.40	1.92	1.18
10:00	2.74	3.09	2.97	3.87	3.16	2.71	2.00	2.22	2.24	2.36	2.63	2.84	2.02	1.32
10:15	2.59	3.26	3.09	3.83	2.84	2.97	2.00	2.24	2.26	2.36	2.47	2.91	1.96	1.41
10:30	2.47	3.56	3.22	3.68	2.74	3.09	2.02	2.26	2.38	2.36	2.53	2.74	1.72	1.59
10:45	2.49	3.52	3.22	3.91	2.78	3.24	2.16	2.38	2.38	2.36	2.80	2.76	1.69	2.28
11:00	2.51	3.52	3.44	4.24	2.99	3.38	2.30	2.40	2.51	2.40	2.78	2.78	1.96	3.30
11:15	2.69	3.54	3.91	4.18	3.44	3.36	2.55	2.77	2.49	2.65	2.93	2.93	2.19	2.51
11:30	2.97	3.70	3.83	3.98	3.56	3.38	2.67	3.50	2.49	2.47	2.93	2.93	2.38	2.32
11:45	3.11	3.70	3.64	3.87	3.68	3.54	2.80	3.72	2.49	2.49	3.09	3.05	2.22	2.34
12:00	3.40	3.89	3.50	4.26	3.45	3.50	2.95	3.68	2.51	2.49	3.20	2.91	2.20	2.18
12:15	3.38	4.06	3.54	4.44	3.16	3.38	3.09	3.68	2.67	2.51	3.03	3.09	1.96	1.96
12:30	3.56	4.20	3.70	4.80	3.22	3.70	3.26	3.68	2.78	2.67	3.05	3.24	2.00	2.00
12:45	3.68	3.98	3.68	4.78	3.38	3.50	3.54	3.64	2.74	2.82	3.09	3.34	1.98	1.98
13:00	3.48	3.79	3.68	4.95	3.36	3.52	3.30	3.32	2.63	3.11	3.42	2.95	1.87	1.85
13:15	3.32	3.45	3.66	4.74	3.34	3.52	2.97	3.34	2.76	3.24	3.52	2.53	1.87	1.74
13:30	3.16	3.30	3.50	4.78	3.20	3.50	2.70	3.16	2.65	3.36	3.32	2.28	1.78	1.63
13:45	3.01	2.99	3.54	4.95	3.40	3.30	2.59	3.03	2.93	3.16	3.16	2.04	1.89	1.53
14:00	2.91	2.93	3.66	4.72	3.52	2.99	2.47	3.05	2.70	2.99	3.07	1.81	1.72	1.45
14:15	3.05	3.24	3.30	4.59	3.30	2.89	2.47	3.05	2.43	2.68	3.38	1.63	1.51	1.51
14:30	2.87	3.18	3.16	4.95	2.97	2.89	2.34	3.07	2.32	2.41	3.12	1.69	1.49	1.69
14:45	2.74	3.05	3.03	4.55	2.72	2.76	2.36	3.20	2.22	2.16	2.70	1.80	1.75	1.55
15:00	2.78	3.22	3.05	4.76	2.74	2.93	2.38	3.01	2.24	1.94	2.76	1.80	1.92	1.59
15:15	2.97	3.18	3.03	4.50	2.63	2.91	2.49	2.87	2.24	1.85	2.76	1.94	1.87	1.67
15:30	3.26	3.05	2.85	4.18	2.80	2.91	2.32	2.74	2.22	1.76	2.78	2.18	1.78	1.53
15:45	3.42	3.20	2.65	4.42	2.93	2.99	2.22	2.78	2.08	1.78	2.97	2.28	1.94	1.43

	Flowrate (m3/h)													
Time	**16 March**	**17 March**	**18 March**	**19 March**	**20 March**	**21 March**	**22 March**	**23 March**	**24 March**	**27 March**	**28 March**	**29 March**	**30 March**	**31 March**
16:00	3.72	3.01	3.11	4.57	2.93	3.56	2.24	2.93	1.98	1.78	3.20	2.34	2.12	1.38
16:15	3.66	2.89	3.05	4.34	3.05	3.14	2.24	2.89	2.00	1.80	2.84	2.04	1.83	1.49
16:30	3.48	2.89	3.05	4.20	2.89	3.03	2.28	2.74	2.00	1.94	2.78	1.83	1.78	1.45
16:45	3.36	2.74	3.05	4.44	2.91	3.05	2.55	2.76	2.02	2.18	3.11	1.76	1.91	1.38
17:00	3.52	2.74	3.07	4.82	2.91	3.03	2.67	2.76	2.14	2.32	3.22	1.76	1.89	1.55
17:15	3.34	2.61	3.24	4.93	2.91	2.91	2.78	2.78	2.16	2.75	3.18	1.65	1.89	1.85
17:30	3.42	2.65	3.42	4.50	2.91	3.09	2.78	2.93	2.44	3.26	3.01	1.71	1.89	1.92
17:45	3.97	2.80	3.74	4.36	2.89	3.26	2.93	2.95	2.67	4.50	2.87	1.96	1.87	2.06
18:00	4.42	2.95	3.87	4.36	2.76	3.56	2.91	3.24	2.65	5.77	2.76	2.18	1.76	2.32
18:15	4.16	3.09	3.83	4.16	2.95	3.52	2.91	3.20	2.85	6.03	2.95	2.26	1.76	2.57
18:30	3.98	3.22	3.68	4.00	3.11	3.52	2.91	3.18	3.28	5.72	3.05	2.22	1.67	2.80
18:45	3.81	3.20	3.89	4.02	3.42	3.52	2.93	3.05	3.40	5.32	2.89	2.12	1.80	2.78
19:00	3.62	3.22	4.00	4.02	3.54	3.52	3.09	3.22	3.56	5.34	2.95	2.24	1.78	3.01
19:15	3.32	3.38	3.64	4.04	3.52	3.52	3.22	3.22	3.70	5.13	3.24	2.08	1.78	3.62
19:30	3.34	3.34	3.68	4.20	3.52	3.50	3.24	3.36	3.68	5.20	3.22	1.96	1.76	3.60
19:45	3.18	3.16	3.70	3.98	3.52	3.32	3.54	3.20	3.66	5.64	3.36	1.87	1.65	2.74
20:00	3.20	3.03	3.85	3.83	3.52	3.14	3.34	3.38	3.52	5.81	3.16	1.87	1.67	2.37
20:15	3.22	3.07	3.68	3.85	3.52	2.87	3.36	3.36	3.72	5.76	3.01	1.74	1.69	2.00
20:30	3.36	3.20	3.87	3.83	3.52	2.93	3.34	3.38	3.87	5.48	2.89	1.63	1.78	1.70
20:45	3.18	3.01	3.83	3.64	3.52	3.07	3.16	3.54	3.85	4.82	2.91	1.53	1.63	1.61
21:00	3.22	2.87	3.64	3.48	3.50	3.05	2.99	3.50	3.87	4.27	2.89	1.45	1.53	1.43
21:15	3.40	2.74	3.48	3.34	3.36	3.07	2.70	3.34	4.06	3.98	2.74	1.47	1.43	1.47
21:30	3.58	2.76	3.34	3.42	3.52	3.20	2.63	3.34	4.28	3.98	2.78	1.49	1.34	1.47
21:45	3.87	2.78	3.36	3.89	3.36	3.01	2.78	3.20	4.87	3.60	2.97	1.61	1.25	1.47
22:00	3.60	2.93	3.36	3.62	3.52	2.87	2.76	3.38	5.22	3.28	3.22	1.69	1.20	1.49
22:15	3.12	2.93	3.32	3.30	3.34	2.70	2.76	3.36	5.43	2.95	3.01	1.67	1.32	1.61
22:30	3.03	3.11	2.99	3.18	3.32	2.45	2.78	3.38	5.81	2.53	2.87	1.67	1.45	1.71
22:45	3.05	3.36	2.89	3.20	2.97	2.51	2.91	3.52	5.50	2.26	2.72	1.63	1.69	1.78
23:00	3.01	2.97	2.91	3.18	2.66	2.65	2.72	3.28	5.07	1.90	2.57	1.41	1.41	1.61
23:15	2.68	2.68	2.87	3.01	2.24	2.61	2.57	2.78	4.69	1.76	2.30	1.32	1.32	1.40
23:30	2.43	2.43	2.55	2.89	1.90	2.45	2.28	2.39	4.52	-	2.20	1.13	1.14	1.25
23:45	2.30	2.30	2.30	2.87	1.68	2.30	2.06	2.16	4.34	-	2.06	0.98	1.08	1.31

Appendix II (C)

ANOVA table – Discharge flow rate on dry days in dry season 2016 (Chapter 5)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	456.638	25	18.266	19.834	2.8E-80	1.511
Within Groups	2262.689	2457	0.921			
Total	2719.326	2482				

ANOVA table – Discharge flow rate on weekdays and weekends in dry season 2016 (Chapter 5)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	29.196	1	29.196	26.926	2.2853E-07	3.845
Within Groups	2690.131	2481	1.084			
Total	2719.326	2482				