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URBAN RUNOFF POLLUTANT SURVEY AND SWMM SIMULATION IN VIENTIANE CAPITAL, LAO PDR

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This study is highlighted to survey changes of pollutant in runoff water from a core urban area of Vientiane City, Lao PDR during dry and rainy seasons, and to simulate the runoff pollutant by using SWMM simulation model. Hong Thong catchment area was selected for sampling during wet and dry weather. As a result of the surveys, mean concentration of SS was higher in a rainy season, in contrast, COD, TN and TP were much higher in a dry season possibly due to being associated with domestic wastewater and attenuation by stormwater in a rainy season. The mean total PAHs concentration values were 230.13, 132.83 and 143.72ng/L respectively for a rainy season wet and dry periods, and a dry season. In addition, the pollutant runoff from the catchment area was simulated using SWMM, and the runoff characteristics were shown.

Key Words*: *Developing Country; pollutant runoff; simulation; SWMM; urban runoff; Vientiane

1. INTRODUCTION

Urban runoff is one of the main important sources of pollution, which causes water quality deterioration with high pollutant loads including sediment, nutrients, heavy metals, oils and hydrocarbons, and oxygen demanding substances[1)]. Polycyclic aromatic hydrocarbons (PAHs) are a class of diverse organic compounds containing two or more fused aromatic rings of carbon and hydrogen atoms. Anthropogenic input from incomplete combustion, oil spills, urban runoff, domestic and industrial wastewater discharges, as well as atmospheric fallout of vehicle exhaust and industrial stack emission have caused significant accumulation of these compounds in the environments[2)]. On the other hand, inappropriate and inadequate drainage systems and sanitation are some of the major environmental problems facing unplanned urbanization in Vientiane Capital City, Lao PDR. The poor drainage of wastewater from septic tanks and poorly designed on-site sanitation have created a major concern for public health, causing widespread pollution of surface water and groundwater[3)]. Most of sewage water together with stormwater is discharged directly into rivers and wetlands without any kind of treatment. The ongoing depletion of water quality has consequences not only on human but also on environmental health. However, little information is available on storm runoff pollution from urban areas in developing counties, including Lao PDR that highlights the significance of this study. The original objectives of this study are to survey changes of pollutants in runoff water from a core urban area, and to simulate the runoff pollutant by using the SWMM model in Vientiane City for the purpose of managing and improving drainage conditions in the city.

2. METHODOLOGY

The study area is situated in the central part of Vientiane capital urbanized area along the east bank of the Mekong River. The study catchments (Fig.1) having an area of 205 ha with population of 14,674[4)] can be categorized into two main land use type (residential, and commercial area) considered as a sub-catchments of major tributaries of main drain channel (Hong Thong Channel), before discharging into That Luang Marsh which is connected to the downstream at Mekong River. The study area lies in a tropical region, with significant monsoon characteristics. The south-western monsoon causes rainfall from May until October as a rainy season and, a dry season is from November to April. The mean annual precipitation is approximately 1,700mm[5)].

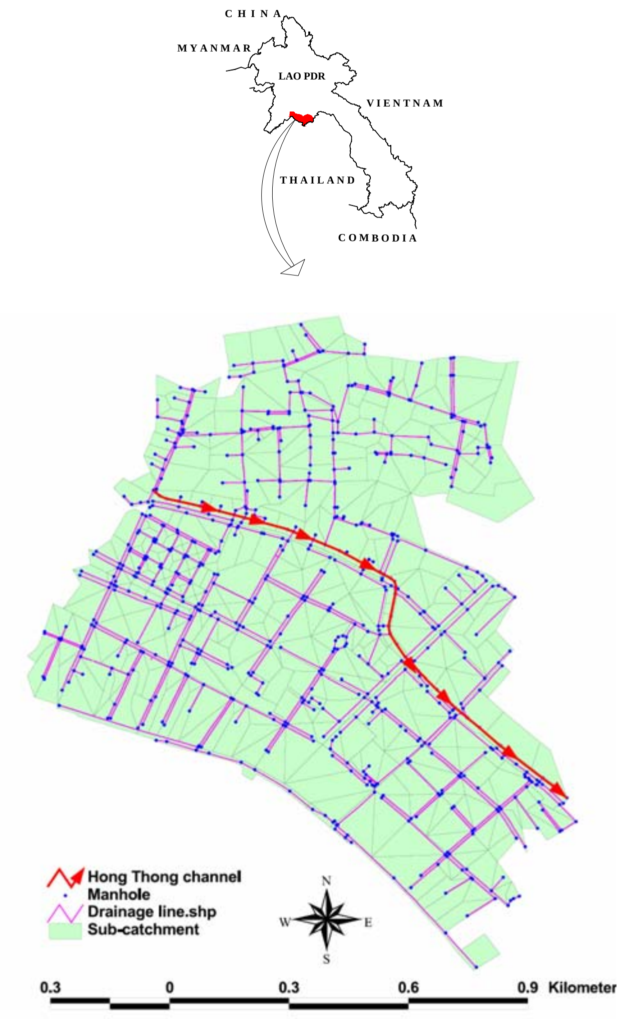

Fig. 1 Outline of drainage network of Hong Thong catchment area.

(1) Water quality investigation

5-12 water samples per day were collected manually at the channel outlet during one week in rainy season, August 2007. And the discharge was continuously measured through rectangular weir by an automatic water level logger. Rainfall data was recorded by an automatic rain gauge near the sampling site. In addition, the same survey in dry season was also carried out in March 2008. All water samples were collected in plastic bottles and transported to a laboratory for analysis in Japan. Suspended solids (SS), chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) were measured according to standard methods, and PAHs were measured by GC-MS (Gas Chromatography/Mass Spectrometry) after the sample water was extracted into dichloromethane according to US EPA Method 525.2[6)].

(2) Hong Thong Catchment SWMM Model

The use of geographical information systems (GIS) has been an essential part of the simulation. In order to take advantage of the digital information, a GIS interface was created to process and generate SWMM input files such as manholes, drainage pipes and catchment. A detailed creating of study catchment area was carried out by using maps and data book of JICA survey in 2002 on drainage condition in Vientiane city[5)]. First, all the catchment area were located on the map by digitizing the printed maps. The drainage area was delimited to each sub-catchment according to the survey of JICA study. As a result of this, there are a total of 451 sub-catchments (sewer pipes and manholes) in 35 zones.

SWMM (Stormwater Management Model) is a dynamic simulation model to simulate single or long-term (continuous) storm events on the basis of rainfall (hyetograph) and other meteorological inputs and systems (characterization, catchment, conveyance and storage/treatment) to predict outcomes in the form of quantity and quality values primarily urban areas[7)]. In SWMM, pollutant accumulation in an urban surface is shown by Eq.(1), and its runoff is shown by Eq.(2) [8)].

$$DD = DD_{Limit} \cdot X \cdot (1 - e^{-c \cdot t}) \quad \ldots (1)$$

where *DD*; cumulative accumulated loads (kg), DD_{Limit}; maximum accumulated loads (kg/ha), *X*; catchment area (ha), *c*; accumulation index (1/d), *t*; dry period (d).

$$L_1 = PSHEDO(1 - e^{-K \cdot t'}) \quad \ldots (2)$$

$$K = a \cdot R^b \quad \ldots (3)$$

where L_1; cumulative runoff loads (kg), *PSHEDO*; initial accumulated loads (kg), *t'*; duration period of rainfall (hr), *K*; coefficient of runoff rate (mm/hr), *a*; coefficient, *R*; rainfall intensity (mm/hr), *b*; index. When *b*=1, the power *Kt'* in Eq.(2) contains the product of runoff rate *a*(1/mm) and rainfall precipitation *Rt'*(mm).

There is no observed water quality data for the Hong Thong catchment area. Literature data for pollutant accumulation and runoff coefficients are used to build the Hong Thong catchment SWMM water quality model. Various studies were carried out in an effort to monitor the accumulation and runoff of pollutants on various land use categories. For example, using water quality data from Lake

Biwa basin in Japan, parameters for each equation were determined for each land use based on results of several surveys on pollutant accumulation/runoff on urban surfaces[9),10)]. Here, versatile parameters determined from various surveys without curve fittings[9),10)] were used because the authors had an importance upon simulation analysis and discussions rather than simulation accuracy. A comprehensive summary of accumulation and runoff parameters for various land uses were given in Table 1. The other parameters used for the simulation were default values.

Table 1 Model parameters.

Index and land use*		Accumulation		Runoff	
		DD_{Limit}	c	a	b
SS	R	91.34	0.070	0.029	1.000
	C	253.68			
COD	R	3.96	0.054	0.058	1.000
	C	10.49			
TN	R	0.14	0.095	0.048	1.000
	C	0.27			
TP	R	0.03	0.121	0.067	1.000
	C	0.01			

* Land use R: residential, C: commerical

3. RESULTS AND DISCUSSION

(1) Water quality investigation

Fig.2 shows the combining runoff volume and water quality data that produce hydrograph and pollutograph during a rainy season (with 58.0 mm of precipitation) and a dry season (with no rainfall). In the rainy season, the pollutant concentration peak in the storm event is not clear. After the flow peak, the pollutant concentration rapidly reduced. The rain pattern influenced the interval between the pollution peak and flow peak. The phenomena of first flush also did not clearly occurred for storm events monitored in Hong Thong catchments. Because stormwater quality was measured only the partial storm event, entire storm event might not be fully captured.

Measured concentration ranges of SS, COD, TN and TP during storm events were 8.55-140.80 mg/L, 5.84-12.16 mg/L, 3.95-11.44 mg/L, and 0.68-1.85 mg/L respectively. Mean concentration of SS was relatively low during low flow (dry days in the rainy season and the dry season) but was substantially higher during storm events due to increased runoff bringing particulate material into the channel, which indicates that those sediments in the catchments can freely move in response to runoff of stormwater. In contrast, concentration of COD, TN and TP were greater in the dry season than in the rainy season, the behavior and seasonal variation of COD was quite similar to TN and TP in both seasons. Therefore, possibly due to the attenuation by stormwater, a large component of COD, TN and TP is inferred to derive from the same source associated with domestic wastewater.

The detected concentrations of PAHs ranged between 0.13-311.31 ng/L for wet weather periods in the rainy season, 011-91.6 ng/L for dry periods in the rainy season and 0.09-145.93 ng/L for the dry season with the mean total PAHs concentration value of 230.13 ng/L, 132.83 ng/L and 143.72 ng/L respectively for each period/season. Generally, total PAHs concentration in the rainy season is higher than in the dry season, this implies that PAHs concentration is more influenced by the storm runoff during the rainy season. The sorption of PAHs onto suspended solids in water may be the main contributive factor for the high PAHs concentrations in the rainy season.

The composition pattern of PAHs with benzoyl parts is presented in Fig.3. The PAHs concentration was mainly dominated by 2 and 3 bezoyls in both seasons. Main compound in the PAHs is naphthalene for 2 benzoyls, phenanthrene for 3 benzoyls, pyrene for 4 benzoyls and benzo(a)pyrene for 5-6 benzoyls. The most abundant unsubstantiated individual compounds were naphthalene and phenanthrene. The percentage of the various PAHs provides information regarding possible source of the chemicals, as well as the potential for the components of the mixture to cause adverse health problems. The results in Fig.3 compare the percentage of the various PAHs compounds. More than 80% of all samples collected in storm events and base flow in the rainy and the dry seasons were PAHs with the smaller molecular weight (2 and 3 benzolys). These compounds are generally less toxic and more susceptible to degradation. The lager molecular weight compounds (4-6 benzolys) were less than 20% of the total PAHs. These compounds are both more persistent in environment and human carcinogens. The complex mixtures of PAHs associated with environmental pollution can be classified into two main categories depending on the process of their formation. Petrogenic PAHs are originated from fossil fuels such as petroleum and coal. These PAHs are formed over long periods of time at moderate temperatures. Petrogenic PAHs mixtures are generally rich in the lower molecular weight PAHs (2 or 3 benzoyls). Pyrogenic PAHs are presented in the products of incomplete combustion of biomass and fossil fuels. Pyrogenic PAHs are formed at high temperatures and are generally enriched in higher molecular weight PAHs (4-6 bezoyls). The PAHs detected in

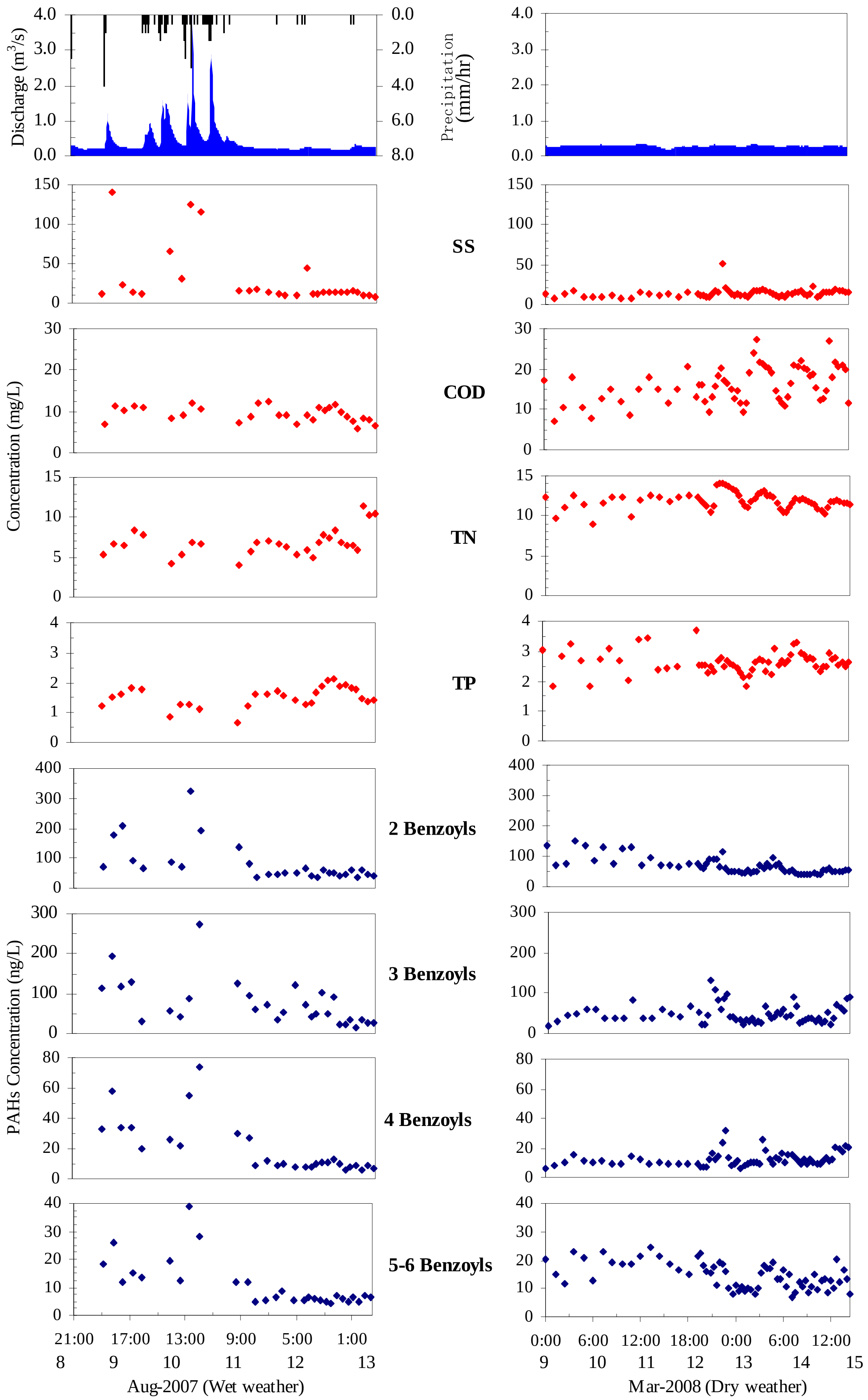

Fig.2 Variation of discharge and concentration of SS, COD, TN and PAHs.

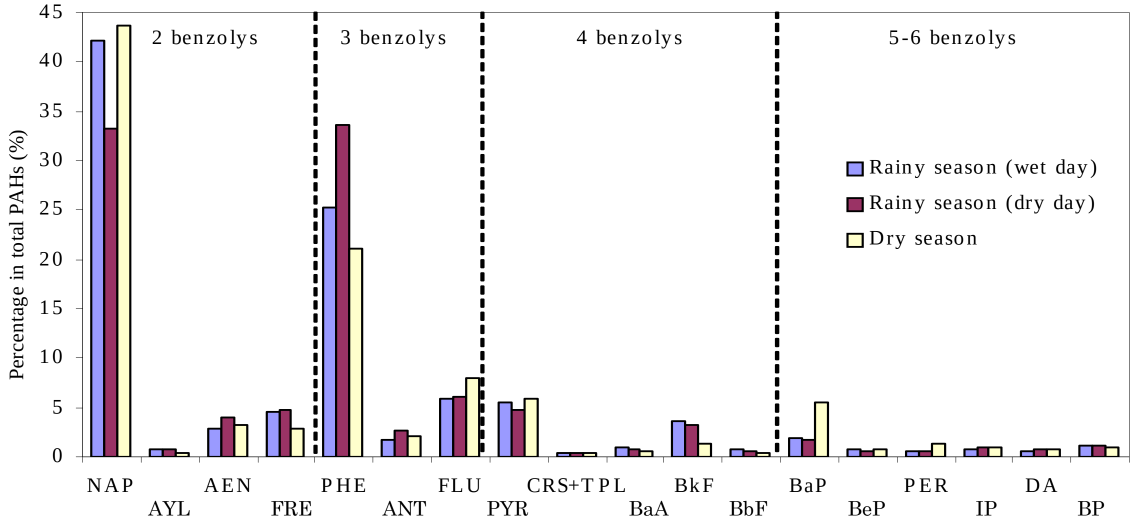

Fig.3 PAHs profile.

water samples from Hong Thong catchment area to originate primarily from petrogenic sources. Concentrations of the low molecular weight PAHs were generally more than 80% of the total PAHs, while the high molecular weight PAH accounted for less than 20% of total PAHs. The profiles of these PAHs showed a possibility that the PAHs derived mainly from oil discharge rather than fuel combustion.

(2) Runoff Simulation Using SWMM

Fig.4 shows a result of the runoff simulation using SWMM for runoff discharge/concentrations during the survey period in the rainy season. The simulations calculated a time series of runoff discharge and pollutant concentrations in 10 minute intervals by inputting a time series of precipitation and base flow data obtained from the runoff survey. The calculated discharge behaves similarly to the observed discharge, and integrated values of the calculated discharge during a storm event correspond to integrated values of the observed discharge. This means enough reproducibility of the simulation for runoff discharge, in consideration of the study purpose. On the other hand, for water concentrations of SS, COD, TN and TP, simulated values fluctuate much according to discharge variation. However, some indices for solid pollutants tend to have relatively low reproducibility, because most parameters were determined from field observations and no fitting procedure. All the parameters are subject to adjustments when the model is calibrated. Average relative error (= |[calculated]-[observed]|/[observed] x 100 %) between calculated and observed runoff discharge is 32.8%. And the average relative errors between calculated and observed runoff concentra-

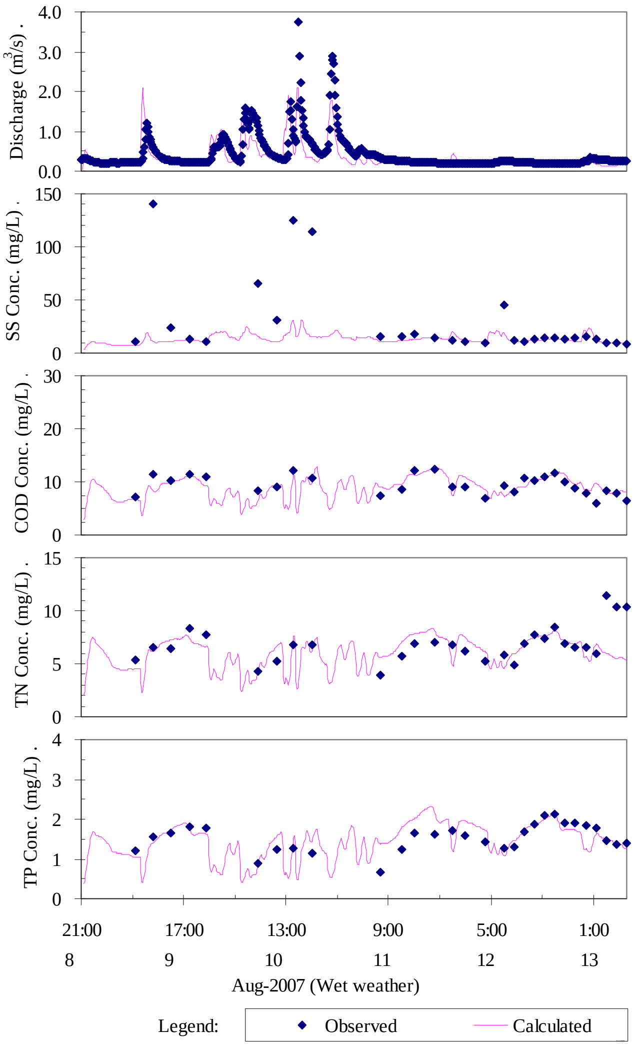

Fig.4 Result of the runoff simulation using SWMM for runoff discharge/concentrations during the survey period in the rainy season.

tions / loads are 28.4% / 44.5% for SS, 12.6% / 23.6% for COD, 17.3% / 26.4% for TN and 17.4% / 24.4% for TP. Meanwhile, correlation coefficient between calculated and observed runoff discharge is 0.711. And the correlation coefficients between calculated and observed runoff concentrations / loads are 0.464 / 0.712 for SS, 0.647 / 0.798 for COD, 0.184 / 0.589 for TN and 0.601 / 0.585 for TP. There are some gaps of runoff peaks between calculated and observed, which cause small correlation coefficients and large average relative errors despite the reproducibility of phenomenon.

4. CONCLUSION

The results of this study confirm that water quality indicator of COD, TN and TP contained high concentration in a dry season and these compounds mainly came from domestic wastewater, and lower in a rainy season due to attenuated by stormwater. However, SS concentration substantially increased during storm events in response to runoff. The results coupled with investigation of appropriate PAHs allowed identification of the primary PAHs source from oil discharge rather than fuel combustion. It shows unique results especially in developing countries compared with the characteristics in developed countries[11]. And, pollutant runoff from urban areas in Vientiane City, Lao PDR was simulated using SWMM. When such simulation function on urban pollutants is added to a watershed management system which were suggested for another watershed in the previous literatures[12),13)], it would be easier to discuss pollutant behavior, such as generation, transportation, accumulation and runoff, on digital maps in computers for the environmental management. Therefore, this initial study provided useful information for the evaluation of water quality and will guide future efforts to identify ways to reduce urban runoff pollutant exposures and ultimately to reduce risks in Vientiane City, Lao PDR.

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