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Assessment of Land Use Impacts on Water Quality in an Urbanized Area: The Case study of Boeng Trabek Catchment, Phnom Penh, Cambodia

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Abstract: *Phnom Penh, the capital city of Cambodia, has had a rapid increase in urbanization in recent decades. As impervious area increases, urban runoff becomes an increasingly more important component of urban non-point pollution. Boeng Trabek catchment is highly susceptible to flash flooding during heavy storm events. This study evaluates the relationship between the peak discharge and water quality, and assess the impact of land use scenarios on urban water quality by applying PCSWMM model. The sample were collected and used to analyze for the particle of the Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Phosphate (PO_4) and Nitrate (NO_3). The land use scenarios were applied by increasing the percentage of 10% and 20% from the baseline imperviousness. Flow and water quality data were monitored during three storm events for calibration and validation. Land use Editor was assigned to achieve the water quality calibration, with the manual determination of buildup and washoff coefficients. The result showed that Chemical Oxygen Demand, Total Suspended Solid and Phosphate corresponded to the peak values during both storm events on September 22nd, 2018 and September 28th, 2018. However, Nitrate contrasted with the peak flow. Furthermore, the overall simulation accuracies of the pollutants concentration for the calibration were $R^2>0.7$, while NSE>0.5 for both storm events. Land use scenarios indicated that the discharge peak and pollutants concentration were increased as the imperviousness increased. However, Q-mean increased slightly about 3% from the baseline, which from 8.098 m^3/s to 8.975 m^3/s when the increasing imperviousness 20%. The study found that the perviousness in Boeng Trabek has less impact on the average flow in the channel. Regarding the pollutants load at the outfall of the catchment, the all targeted pollutant loads has increased between 6% to 9% from the baseline scenario when increasing the percentage of 10% and 20% from the baseline imperviousness. Consequently, understanding the impact of the imperviousness on urban area could be the useful practice for management and decision making in planning and developing on the wastewater treatment plant planning regarding the impervious scenarios.*

Keywords: Boeng Trabek; Buildup and Washoff; Imperviousness; Land Use Change; PCSWMM; Water Quality

1. INTRODUCTION

Rapidly growing populations are adversely impacting water resources at both local and global scale. High population leads to high urbanization, which causes growing and spreads the impervious surfaces area. Impervious surfaces are for examples: rooftop, roads, sidewalks, lawn, parking lots, which are covered by different type of materials such as concrete, asphalt, and stone. Imperviousness has a direct impact on stormwater runoff and water quality. The activity of urbanizing watersheds caused growing and spread the impervious surfaces area which is significant threats to the quality of natural and built environments (Barnes *et al.*, 2001). Storm water generates surface runoff from the washes over the paving watershed areas with such covered materials (Barnes *et al.*, 2001). The rapid growth of pollution-producing industries and the absence of necessary effluent treatment possibly have led to the deterioration of wetland water quality (Yim *et al.*, 2010).

Phnom Penh, the capital city of Cambodia, is located on a flat alluvial plain at the western bank of the confluence of the Tonle Sap River and Mekong River, which grew in population during 1986 to 1998 (JICA, 1999). During this period the city developed with little planning of control, resulting in flooding problems, increased landfill, and poor urban infrastructure (Sothea *et al.*, 2010). Change of land use is one of the major environmental problems and has adverse impacts on water quality (Built *et al.*, 2001). Therefore, a better understanding of land use scenarios impacting on the watershed hydrologic processes, is important for the prediction and mitigation of flood hazard, and also for the development planning, sustainable development and management of the watershed.

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Boeng Trabek is an important catchment for gathering the wastewater during rainy season in the Phnom Penh city, while the outfall of the sewer pipes at the Tonle Sap River are closed because the water level at there, higher than the groundwater of the city (Takeuchi *et al.*, 2005). This catchment plays an important role in receiving the wastewater from other catchments in the rainy season. Following the impacts of the inundation, wastewater quality is also a significant issue to take attention on and to provide additional better management and controlling the storm water quantity and quality generated from the urban catchment area. According to the studies by Takeuchi *et al.* (2005) and Sothea *et al.* (2010), high concentration of pollutants is generated and found from the Trabek catchment among all catchments in the Phnom Penh capital city. Hence, the Boeng Trabek catchment is a study area in this study, to take attention on for providing sustainable development and better future planning. This study aims to evaluate the characteristics of the peak flow discharge and the water quality concentration and to assess the impact of the land use change on the water quality at the outfall of the sewerage in Boeng Trabek area by applying Personal Computer Storm Water Management Model (PCSWMM).

2. METHODOLOGY

2.1 Study Area

Boeng Trabek catchment was chosen as a study area in this study, which is located in the downtown of the Phnom Penh with the catchment boundary area of 548.7 ha (Fig. 1). The previous research showed household wastewater and storm water discharge volumes into this wetland is about 20 million m^3 (Muong, 2004). The combined sewer system in this catchment consists of a series of pipes, culverts and open channels. The study area covers the drainage system about 8 km of which are 3.048 km of opened channels and 5.478 km of pipeline.

Boeng Trabek is an area of concern because of its kink, aging drainage, retention lake and sanitation infrastructures. Furthermore, the mixing of a number of natural effluent and results of historical development such as rapidly increasing population and solid waste have made Trabek lake and other wetlands with low to middle income household, flooded very often.

2.2 Hydrological Data Collection and Water Quality Sampling

Water levels in the channel were collected at 10-minute intervals by directly observing at the outfall of the catchment. All the data were treated by calculating the monitoring data followed the standard of data input before being input into the model We observed the water level during rainfall event in the rainy season from 22, September 2018 to 02, October 2018, and during the low flow of the dry weather. Precipitation data is one of the crucial input parameters for runoff simulation within one or more sub-catchment in the study area. Rainfall data was monitored by automated weather station from CKCC located less than 4km from the catchment, were manually collected in three rainfall events from September to October 2018.

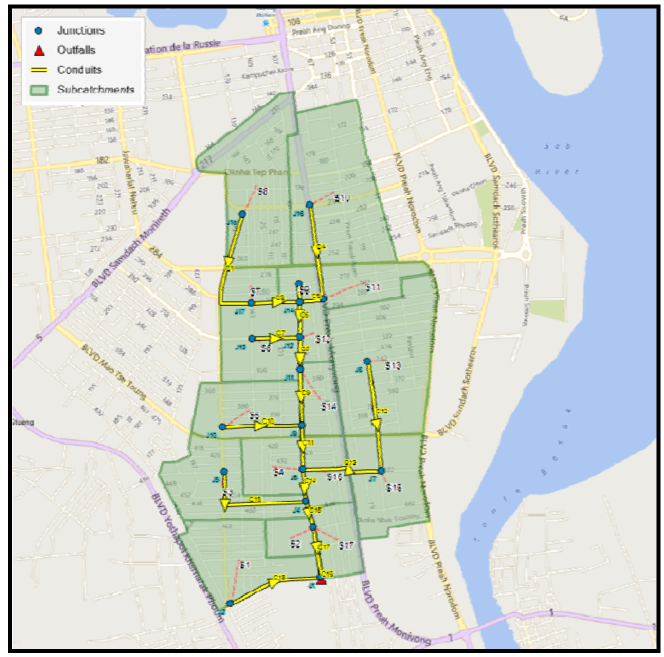

Fig. 1. Boeng Trabek Catchment Boundary, Phnom Penh

Wastewater samples were collected in one site at the conduit 17 of the catchments. Three events of rainfall were used in this study and one low flow collected during the dry weather. The samples were collected in the rainfall event which is known as storm water. The sample of the storm water was collected from the open channel of the sewer combined system which came from the 17 sub-catchments. Grab sampling technique were collected in 3L for each wastewater samples from the main channel. All the storm water runoff samples were used to analyze the particle of the Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Phosphate (PO_4) and Nitrate (NO_3). The samples were refrigerated at laboratory to analysis. The samples were analyzed for COD, PO_4, and TSS by using the method AOAC 973.55, and NO_3 by HPLC method at the laboratory of the Industrial Laboratory Center of Cambodia (ILCC), Ministry of Industry and Handicraft (MIH).

2.3 Land Use Change Scenarios

We separated land use into two types: pervious and impervious areas. The impervious area has effect on the flow and water quality parameters in the drainage system. The present condition of the catchment was taken as the present scenario for the study and is considered as the "Baseline", with the imperviousness calculated through model conceptualization. Akhter and Hewa (2016) have applied their land use change scenarios in seven future scenarios by using the increasing by 10% interval from each scenario, which was increased from zero imperviousness, 10%, 20%, 30%, 40%, 50%, 60% and 70%. In this study, all the sub-catchments also were assigned 10%-20% for the increase of the imperviousness in the reason of the situation of the land use in the catchment area was rich of the building, residential houses, road, and commercial area that those are hardly to change their characteristics to others objects. Two future urbanization scenarios were hypothetically generated in this study: Increase in 10% and 20% of urbanization. Each selected scenario was applied to every sub-catchment and hence the percentage imperviousness within every sub-catchment was increased accordingly from the Baseline Scenario.

2.4 Statistics Analysis

By choosing the SRTC function and selecting calibrate to observed location with parallel running simultaneously, calibrated model results can be displayed. Radio sliders located at the bottom of the window in the PCSWMM calibrated graph allow the user to change the uncertainty value of parameters within the predefined range in order to better match the time series plots. However, discrepancies always occur between observed data and model output due to, among other reasons, inaccurate measurement and imperfect parameterization (Wan and James, 2002).

The model performance during the sensitivity analysis, parameter optimization, and calibration and validation stages was evaluated using criteria that had been applied in other similar studies (Chow *et al.*, 2012; Krebs *et al.*, 2013). There are several methods that quantify model performance in calibration. Those used in this study included the integral square error, Nash–Sutcliffe efficiency, and the coefficient of determination. The integral square error rating (ISE), commonly used to compare the performance of many systems, can vary from excellent (<3) to poor (>25); it is given in below equation. Nash–Sutcliffe efficiency (NSE) indicates how well simulated data match observed data. It can range between -∞ and 1, and values between 0.0 and 1.0 are usually considered acceptable (Moriasi *et al.*, 2007), with NSE=1 indicating a perfect fit. The coefficient of determination *R*2 is a key output of regression analysis, and an *R*2 value of 1 indicates that the regression line perfectly fits the data.

$$ISE = \frac{\sqrt{\sum\left(Q_{obs}-Q_m\right)^2}}{Q_{obs}} \quad \text{(Eq. 1)}$$

$$NSE = 1-\frac{\sum\left(Q_{obs}-Q_m\right)^2}{\sum\left(Q_{obs}-\overline{Q_{obs}}\right)} \quad \text{(Eq. 2)}$$

$$R^2 = \left(\frac{\sum(Q_{obs}-\overline{Q_{obs}})(Q_m-\overline{Q_m})}{\sqrt{\sum(Q_{obs}-\overline{Q_{obs}})^2\sum(Q_m-\overline{Q_m})^2}}\right)^2 \quad \text{(Eq. 3)}$$

Where:

Q_{obs} = measured daily discharge (m³/s)

Q_m = simulated daily discharge (m³/s)

Table 1. Summary of NSE and ISE Rating Performance

NSE	ISE	Rating
0.5 to 1	0 to 3	Excellent
0.4 to 0.49	3.1 to 6	Very good
0.3 to 0.39	6.1 to 10	Good
0.2 to 0.29	10.1 to 25	Fair
<0.2	>25	Poor

A sensitivity analysis was also performed on each physical model parameter and its performance to determine the parameter's influence on the model output based on simulations under various conditions (Edouard *et al.*, 2016). The impact of slope, flow width, flow length and imperviousness were all considered for their effect on the model output.

3. RESULTS AND DISCUSSION

3.1 Sub-catchment Delineation

Sub-catchment identification was one of the most difficult tasks to complete and needed to be accessed carefully to process the calibration effort and accuracy of the model output. The total 17 sub-catchments were digitized for the Boeng Trabek catchment based on the flow direction (Fig. 2).

The enough detail of the calibration would be provided by these above sub-catchments to adequately characterize the types of the surface variable and also the different neighborhoods variables. The two main sewer lines system identified for modelling in the Boeng Trabek were the sewer pipe line and open sewer channel. The model sewer line was combined by a series of connection of pipes and nodes in the sub-catchments, which were defined by the flow direction of the wastewater. The outlet of the model was determined as C19, which is located near the pumping station. This study did not include the pump station operation in the model set up. However, it should be included in the future study.

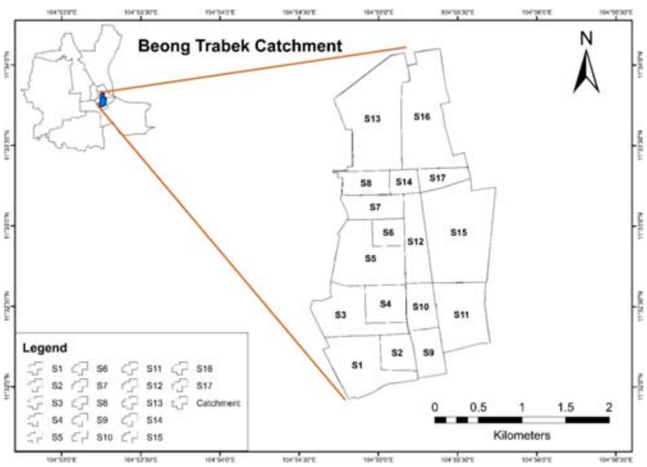

Fig. 2. Boeng Trabek sub-catchments delineated

3.2 Flow Calibration

The PCSWMM tools, Sensitivity-base Radio Tuning Calibration (SRTC) tools, were used to do a calibration on the hydrology. All the three rainfalls events data, which the event on 22 September, 2018 and 28 September, 2018 were used for calibration, and the event on 24 September, 2018 was used for validation. The calibration and verification of the hydrological parameters provided a very good result.

Table 2. Summary result of the baseline flow simulation and calibration

Rainfall data	Max. flow Obs. (m³/s)	Max. flow Sim. (m³/s)	R^2	NSE	ISE	ISE Rating
22/9/2018*	8.723	8.741	0.90	0.71	2.84	Excellent
28/9/2018**	8.231	8.766	0.75	0.74	4.39	Very good
24/9/2018*	7.51	8.863	0.85	0.60	5.35	Very good
24/9/2018**	7.51	8.367	0.86	0.76	4.12	Very good

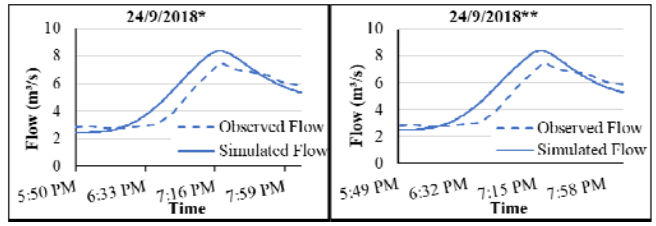

Fig. 3. The simulated and calibrated flow baseline result from rainfall events 22/9/2018 and 28/9/2018

Fig. 3 have shown the accuracy between the simulation and observation. Table 2 represents the well performance of the model, which indicates by the R^2 value, which ranges from 0.7 to 0.9. The measurement of the goodness fit of the simulation with the observation is well performance, which shows NSE values greater than 0.6 for both calibration and validation, respectively.

3.3 Water Quality Calibration

To reach the target of the study, the calibration of hydrological module was needed to estimate the non-point pollution in the study area. Then, the calibration result of the hydrological parameters was used for the input of the model and used to calibrate and validate the selected water quality parameters. There are two steps to do the calibration of the water quality. Firstly, the previous data range of the buildup and wash-off parameters were used for the input of the model.

Table 3. Calibration of water quality parameters

	Pollutants	Rain Data	NSE	R^2
Calibration	PO_4	22/09/2018	0.895	0.985
		28/09/2018	0.736	0.988
	COD	22/09/2018	0.729	0.739
		28/09/2018	0.845	0.956
	NO_3	22/09/2018	0.558	0.984
		28/09/2018	0.9	0.912
	TSS	22/09/2018	0.608	0.767
		28/09/2018	0.724	0.861

The buildup and wash-off parameters were adjusted in the calibration process. For the second step, the model parameters were manually adjusted for all the pollutants of the model which contributed to the outfall observed until the result of the calibration matched the observed data. The optimal parameters of the water quality module TSS, COD, NO_3, and PO_4 obtained from the calibration gave a good result is shown in Table 3. The well performance of the model for the two rainfall events 22 September, 2018 and 28 September, 2018 were represented by R^2 values greater than

0.7, while the goodness fit criteria NSE values were greater than 0.5, respectively.

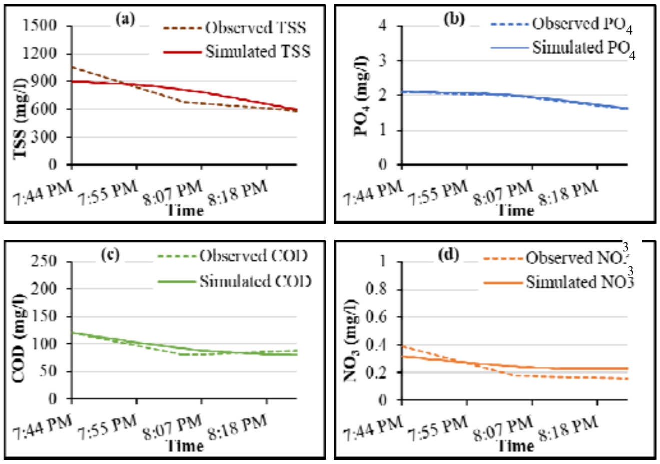

Fig. 4. The simulated and observed of the water quality on the rainfall event 22/9/2018; TSS (a), PO_4 (b), COD (c), NO_3 (d)

However, the model validation of these four parameters have shown the poor result values for NSE and weak goodness of R^2 values. Since the weak goodness of these water quality parameters cannot be modelled by simply using several rainfall events in the current study area. Li *et al.* (2016) also reported that because of the weak goodness-of-fit of TSS, then TSS cannot be modelled by simply using rainfall data from several events in the study area. It may be possible more to improve the validation results with more observed samples and rainfall data.

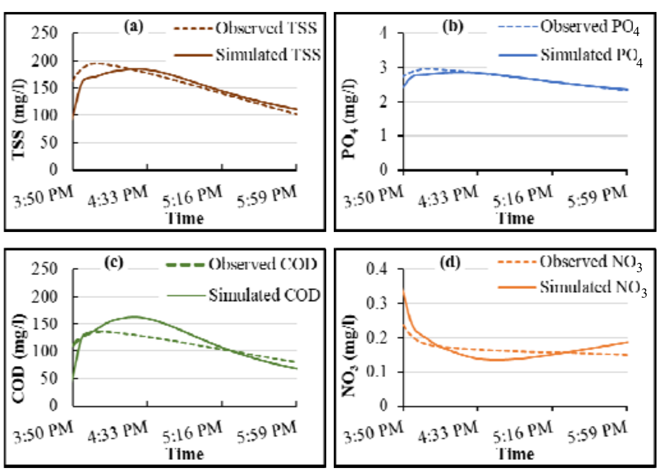

Fig. 5. The simulated and observed of the water quality on the rainfall event 28/9/2018; TSS (a), PO_4 (b), COD (c), NO_3 (d)

3.4 Characteristics of Water Quality and Discharge

Combining runoff quality and flow data at Boeng Trabek catchment produces pollutographs. The pollutographs of pollutants from the two rainfalls event are shown in Fig. 6 and Fig. 7. The peak concentration of TSS and PO_4 preceded the peak runoff flow rate during the two rainfall events. COD shows decreasing concentration at the rainfall event 22 September, 2018. It tends to decrease with the runoff flow rate increase. On contrary, COD concentration shows higher level as TSS and PO_4 concentration at the early and the peak stage of surface runoff for the rainfall event 28 September, 2018. It tends to decrease with the runoff flow rate decrease. Especially for the higher flow rate during high rainfall intensity of the day appears the higher concentration of COD, TSS, and PO_4, which showing the strong flushing effects Fig. 7. This suggests that COD, TSS, and PO_4 sources might be exhausted and subjected to dilution from the surface runoff during the higher rainfall event. HUANG *et al.* (2007) has reported that the higher concentration of COD and TSS precede the peak runoff flow rate. Moreover, the large flood does not appear to reduce the concentration of phosphate (PO_4) as others pollutants (Cordery, 1977).

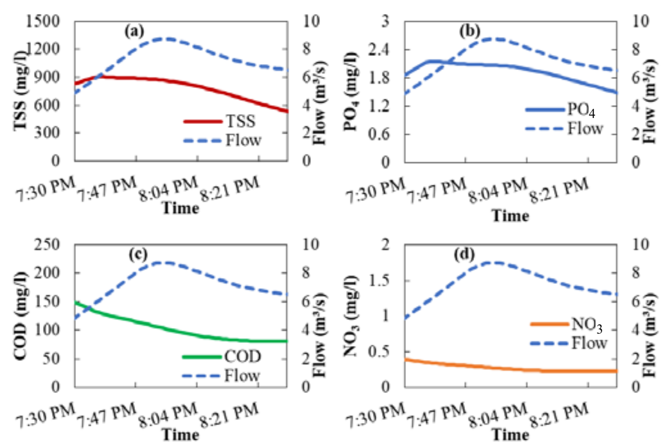

Fig. 6. The characteristics of the flow with the water quality parameters for 22/9/2018; TSS (a), PO_4 (b), COD (c) and NO_3 (d)

The tendency of the concentration COD, TSS and PO_4 changing with the runoff flow rate varied between rainfall intensity. In contrary, the peak concentration of NO_3 precedes the decrease of the flow rate. NO_3 concentration shows higher level at the lower stage of the flow rate. The peak runoff flow rate countered to the peak concentration of NO_3. The study by Cordery (1977) also indicated that nitrate (NO_3) concentration varies very little during the passage of a flood except to decrease slightly during and after peak flows.

The flow characteristics from the rainfall intensity and land use in the study catchment influences the profile of the pollutant concentration. Lower rainfall intensity (rainfall event 22 September, 2018) has made rainfall slowly infiltrate, generate the surface runoff, and wash off the pollutants on the surface of the catchment. Precipitation water generally contains phosphorus in very small concentrations. Urban runoff may be contaminated by phosphorus originating in, for instance, fertilizers used in urban gardening, birds' droppings, and animals' excreta. In urban area, these sources are the factor of producing phosphate. The storm event has made the flow increased with the rainfall intensity, then wash the pollutants from the land use in the catchment through the surface runoff into the drainage.

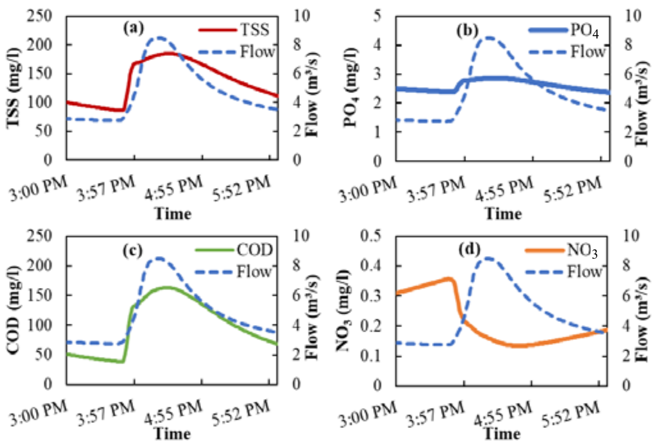

Fig. 7. The characteristics of the flow with the water quality parameters for 28/9/2018; TSS (a), PO_4 (b), COD (c) and NO_3 (d)

3.5 Impact of Land Use Change on Discharge

Regarding to the better performance of R^2 and NSE during the calibration of the hydrology and water quality parameters on the rainfall event 28 September, 2018. Therefore, the land use scenarios will use only the rainfall event on 28 September, 2018 to simulate both the baseline and land use scenarios.

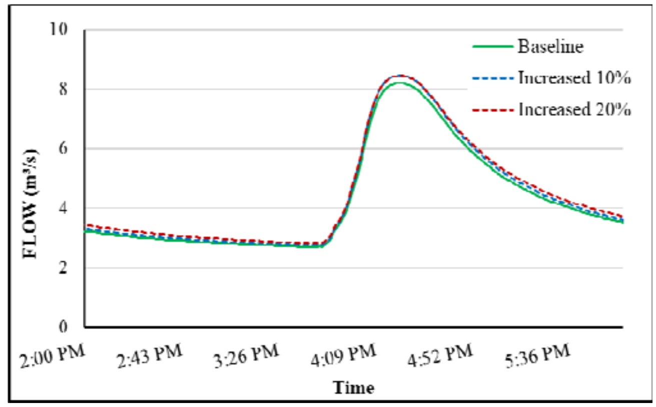

Fig. 8. Comparison the effect of land use scenarios on flow

The simulation represented the variation of hydrology in the drainage system within the land use change scenarios. Fig. 8 indicated that while the impervious area increased, the discharge was increased together. The discharge has much changed between the Baseline and the both scenarios as the peak discharges occurred. However, there was slightly changed over the scenario "Increase 10%" and "Increase 20%", as shown in the figure, by the reason of the imperviousness has reached to the limitation of development. The maximum discharge varied in ranged 8 m³/s to 9 m³/s within the land use change scenarios.

3.6 Impact of Land Use Change on Daily Mean Flow (Q-mean)

Daily mean flow (Q-mean) is an indication of average stream flow conditions. The mean flow in Boeng Trabek catchment increased slightly from 8.766 m³/s to 8.975 m³/s while urbanization increased. Fig. 9 represents the overall variation of Q-mean increased 2% when urbanization increased 20%.

There was increasing trend in the mean flow and the increase could be the result of increased overland flow as land use reduces infiltration. The changes in mean flow can cause deterioration in stream conditions and new channels could be formed, leading to new floodplains and ultimately problems for local residents and industrials. Wella-Hewage (2013) concluded that increases in mean flows lead to deterioration in channel banks and ultimately new flood plains are generated. Bledsoe and Watson (2001) found that urbanization also led to the destabilization of river banks as a result of increased runoff and mean flows.

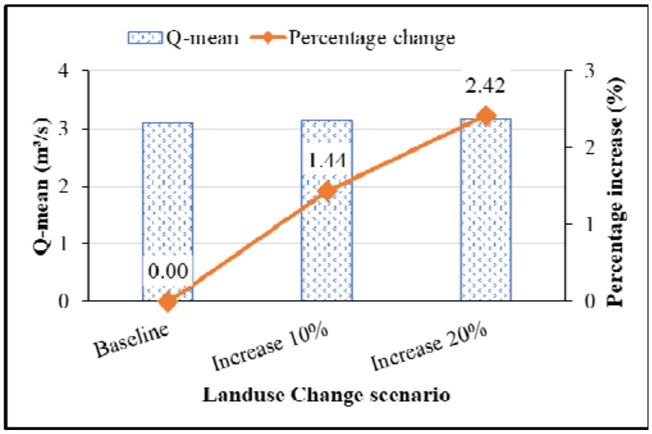

Fig. 9. Urbanization effects on mean daily flow

3.7 Impact of Land Use Change on Water Quality

The graphics below have shown that effect of land use scenarios on the water quality parameters. The storm water quality under the imperviousness increased was higher than under the baseline. Heavy metal contamination has increased while the impervious cover increased, which this can be a primary reason for the concentration of water quality being relatively higher. Fig. 10 indicated that TSS has increased 7.55% as the imperviousness increased 20%. A possible reason causing the increasing levels of pollutants could be due to an expansion of impervious area, vegetation loss and soil alteration (digging and filling). The increasing of the TSS load could be cause by the producing of dust and eroded sediment from the sub-catchment imperviousness such as road, roof, or lawn yard, that were brought into the drainage system during the storm events. COD has also increased 6.12% from the baseline load, as shown in Fig. 11. Gromaire-Mertz et al. (1998) has reported that the increasing of the COD and TSS was the result from roof runoff and land use during the rainfall intensity, which included the ground washoff the yard and street runoff. NO_3 and PO_4 has slightly increased by 8% over the baseline load, are shown in Fig. 12 and Fig. 13. A high precipitation can cause the amount of stormwater runoff flows into drainage system by decreasing the concentration of the stormwater quality. However, the increasing percentage of impervious cover leads to the acceleration of stormwater runoff flows and washes pollutants into the outfall. PO_4 and NO_3 mostly came from the vegetation activity and little came from the road runoff. In the review by Berndtsson et al. (2010) has indicated that PO_4 and NO_3 concentration are linked to the age of the roof and fertilization. Berndtsson et al. (2006) postulated that organic nitrogen may be released from vegetated roofs. Some studies has found that phosphorus mostly release in the form of phosphate and which are example in green roof (Berndtsson et al., 2006; Bliss et al., 2009). Others have found that the concentrations of total phosphorus in green roof runoff water are significantly higher than concentrations of phosphate phosphorus. Since the catchment is almost fulfilled of impervious area and little green roof or vegetation activity, that led to produce little PO_4 and NO_3 concentration. Then, this little variation could be caused by those reasons.

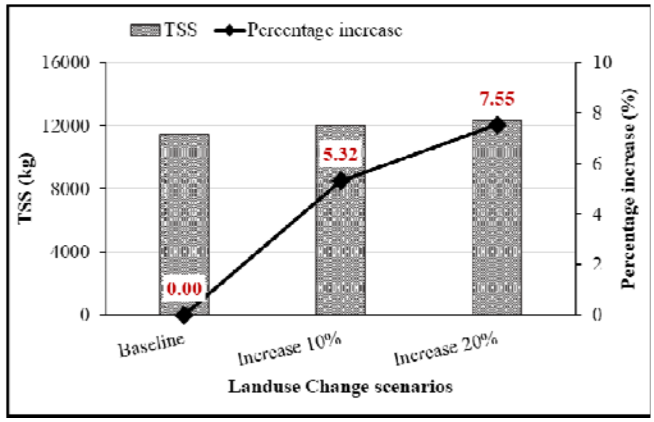

Fig. 10. The effect of land use change on TSS load at the outfall on the rainfall event 28/9/2018

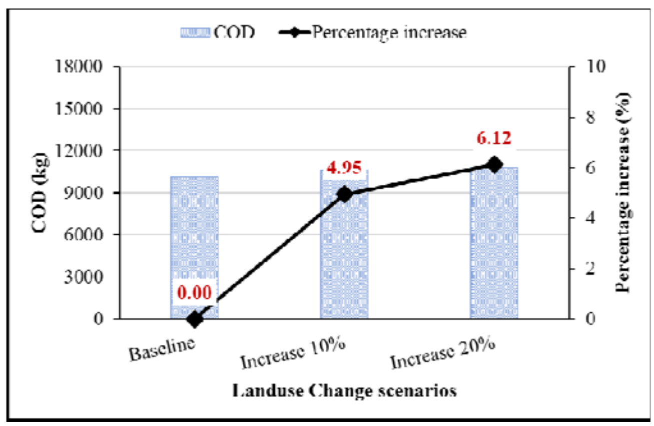

Fig. 11. The effect of land use change on COD load at the outfall on the rainfall event 28/9/2018

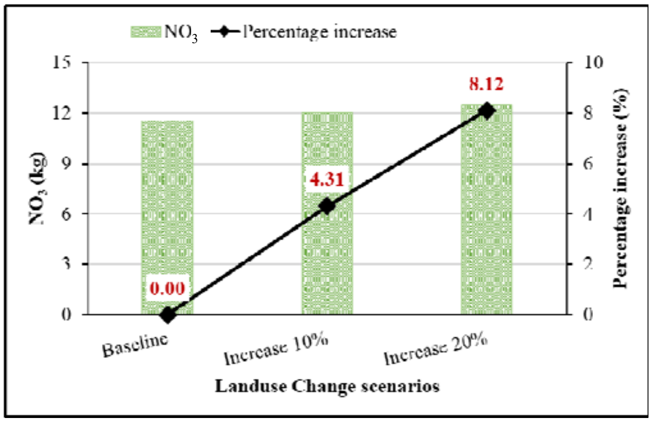

Fig. 12. The effect of land use change on NO_3 load at the outfall on the rainfall event 28/9/2018

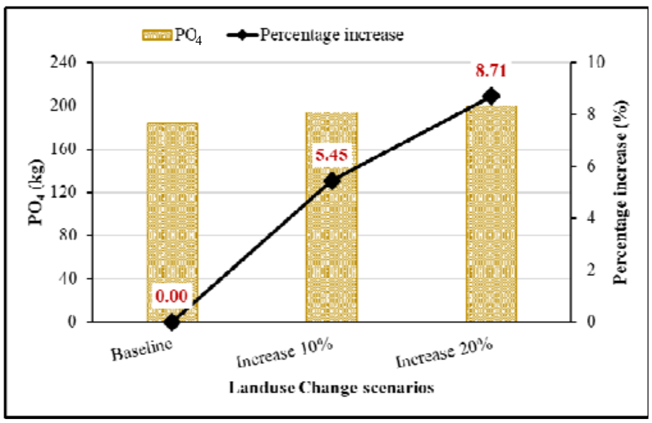

Fig. 13. The effect of land use change on PO_4 load at the outfall on the rainfall event 28/9/2018

In addition, the study by Monterusso et al. (2002) has shown that NO_3 concentration also can be varied between different drainage and soil systems with the thinnest one showing high release. The studies of monitoring and modeling by Schueler (1995) has shown consistently that urban pollutant loads increase with watershed imperviousness.

4. CONCLUSIONS

The hydrology and water quality calibration were completed successfully by applying the two storm events on September 22nd, 2018 and September 28th, 2018 with the intensity rainfall of 10.2 mm and 13.6 mm. The flow maximum was 8.74 m^3/s during the storm event September 22nd, 2018, while it was 8.76 m^3/s during the storm event September 28th, 2018. The study has shown that the concentration of COD, TSS, and PO_4 were reached to the peak values at the same time as the discharge up to the peak values during both storm events. However, the concentration of NO_3 was countered by the peak flow. That these show that the flow was parallel to COD, TSS and PO_4 concentration. In contrast, NO_3 has decreased the concentration as the flow increased, which indicated that peak flow does not effects NO_3. This peak has occurred about 40 minutes after the precipitation occurred. It can be assumed that the peak concentration of the pollutants has been found when the peak flow happened. Thus, the pollutant concentration in the drainage system can be represented by the flow and has closely relationship with the flow volume in the drainage system.

Urban imperviousness is one of the most critical indicators for considering stormwater related environment problems. The variation of the impervious area on every sub-catchment has applied for the land use scenarios. The two scenarios were made up with the increasing of the imperviousness 10% and 20% to all sub-catchments from the baseline imperviousness, which not included Low Impact Development (LID). The land use scenarios were used to simulate water quality load to compare with the baseline imperviousness. The modelling results show that the all the water quality parameters were getting variation through each scenario. While the land use was increased, the load of the water quality parameters were increased together. The study could be the best practice for management and controlling on the next future planning and development of the smart city. It is an important to focus on the wastewater treatment plant after understanding the effect of the limited imperviousness area in the new urban area.

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