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Estimation of non-point source BOD loading in urban area: A case study in Phetchaburi Municipality, Thailand

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ABSTRACT

The purpose of this study was to develop the equation for the BOD loading estimation from the non-point source wastewater in an urban area. Phetchaburi Municipality area was used as a case study. Here, the non-point source wastewater areas can be classified into two groups according to their land uses and runoff coefficients. One is the construction building areas having a runoff coefficient in the range of 0.50-0.90 such as commercial areas, government offices and roads. The other is the natural and agricultural areas having runoff coefficient in the range of 0.03-0.30 such as rice paddies, mixed orchards, forests, marshes and swamps. The amount of storm water passing through each of these non-point sources was the independent variable. X_1 was the amount of storm water from construction and buildings areas and X_2 was that from the natural and agricultural areas. The average of BOD loading during the dry season used to calculate the BOD loading from the noin-point source wastewater was 208.29 kg/day with the standard deviation at 57.89 kg/day. It was also found that the BOD loading from the non-point source wastewater (Y) and the storm water that flows through the first and the second groups were significantly related. By using the weighted least squares method, the equation was $\hat{Y} = 0.794X_1 - 25.455X_2$. The coefficient of determination was 36.2% and the sum of squared error was 156.78.

Keywords: BOD loading; estimation; non-point sources

1. INTRODUCTION

Wastewater is a major problem which needs to be resolved continually because it is caused by the wastes from houses, communities, industrial factories, and agriculture. These factors bring about different elements of wastewater, so we can classify types of wastewater according to its characteristics or its origin (Sirianuntapiboon, 2006). Wastewater problems can be resolved by reducing its waste level to standard level before discharging into the environment. The main cause is not only the community since the rise in the number of people increases the use of water resources continuously but also rain wash-up the dirt. Presently, the wastewater collection system and wastewater treatment plant were created for the community. In Thailand, combined sewer system is usually used to collect wastewater from houses or point source (Pantumsinchai, 1995) then combines with non-point source wastewater caused by rain wash-up the dirt (Panswad, 2006). Considering to the domestic wastewater, it consists of organic substances such as leftover food, dirtiness from kitchens, and community activities

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(Tulyasathien et al., 2001) while the characteristics of run-off wastewater depend on the land uses of the community (Theppitak, 2000). However, the calculation formulas for BOD from the point source wastewater are available, except for the non-point source wastewater (Pollution Control Department, 2008). Therefore, the wastewater estimation from the non-point source is valuable for increasing the efficiency on the BOD estimation. The total BOD estimated from both of the point source and non-point source will be used to design the combined wastewater system of cities having the combined sewer system.

This study aims to estimate the BOD loading from the non-point source wastewater in the municipality of Phetchaburi by using the amount of storm water.

2. MATERIALS AND METHODS

2.1 Data

The data collected from various sources were used, as follow.

1) The amount of wastewater per day (Unit: m^3) in Phetchaburi Municipality from 2007 to 2012 was provided by the Department of Water Quality Management, Bureau of Engineering, Phetchaburi Municipality.

2) The BOD concentration (Unit: mg/L) of untreated wastewater through Phetchaburi Municipality wastewater treatment plant was archived from The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project.

3) The data of Phetchaburi Municipality land use from 2007 to 2012 was provided by Land Development Department.

4) The satellite images from the LandSAT 5 in 2008 and 2010 and those from the QuickBird in 2009 were gathered from Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA).

5) The amount of rainfall data (per day) over Phetchaburi Municipality measured by the rainfall measurement station at Muang District Agricultural Extension Office and archived by Thai Meteorological Department.

2.2 Research procedure

1) The data of the amount of wastewater (per day) in Phetchaburi Municipality was picked up only the data corresponding to the wastewater quality data which was analyzed at the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project. They consisted of the data from 2007 to 2012.

2) The monthly average amount of wastewater was analyzed to describe the characteristics of wastewater during the study period. Also, the monthly highest amount and the lowest amount of wastewater were described.

3) The monthly data of wastewater was classified according to the season; rainy and dry season. Then the BOD loading (kg/day) in each month was calculated.

4) The monthly BOD loading data during the dry season was grouped together by the rain free duration (days). Then the difference of the average among these groups was analyzed by analysis of variance (ANOVA). Significant difference ($p \leq 0.05$) among these groups was tested by Duncan's multiple range tests. For these sets of data having no differences from each other, the average will be calculated for the representative of the BOD loading during the dry season. This representative was the BOD loading from the point sources, i.e. the wastewater from the houses and buildings in the communities.

5) In the rainy season, the BOD loading was the dirt accumulation from both of the point sources (wastewater from the housing and building in the communities) and the non-point sources (wastewater from roads garbage accumulation areas and the agricultural areas, etc.) by rain washing up. Then, the BOD loading from the non-point sources was

calculated by excluding the influence of the BOD loading from the point sources as calculated in item 4 from the BOD loading during the rainy season.

6) The size of the land use during the study period was analyzed by using the satellite images data from Land SAT 5 and Quick Bird. According to the land use pattern, the monthly storm water over the land use in the rainy season was calculated.

7) Weighted least squares method was applied suitably for the time series data of this research. The equation was written as the following:

$$\hat{Y}=a+b_1X_1+b_2X_2$$

where $\hat{Y}$ is the estimated amount of BOD loading

from non-point source,

a is a constant value,

b_1 is coefficient of surface flow over the construction and building areas,

X_1 is the amount of rainfall over the construction and building areas,

b_2 is coefficient of surface flow over the natural and agricultural areas,

X_2 is the amount of rainfall over the natural and agricultural areas.

8) The model was examined by making the hypothesis testing about the regression coefficients. The coefficient of determination and the sum of squared error were analyzed. Furthermore, the assumptions of the equation were proved.

3. RESULTS AND DISCUSSION

The characteristic of wastewater over Phetchaburi Municipality

From the data of wastewater amount over Phetchaburi municipality during 2007 to 2012, it was found that the average of wastewater in 2007 was 3,791.49 m^3/day. The amount of wastewater had also increased each year. In 2012, the average amount of wastewater had reached its highest number at 8,128.46 m^3/day. For the monthly average amount of wastewater during this period, the lowest average was in February at 4,699.22 m^3/day and the highest average was in October at 6,238.24 m^3/day. Furthermore, the average amount of wastewater during the rainy season (from May to October for Phetchaburi) was higher than that during the dry season (from November to April for Phetchaburi). All these, the characteristics of wastewater over Phetchaburi Municipality were analysed from the wastewater sample at the station before it flows into the wastewater treatment system. The sample collected from the station for BOD is the representative of the whole area in Phetchaburi Municipality that the combined sewer system was covered. So the concentration of BOD in the collected sample reflected the conditions of the area in Phetchaburi Municipality depending on the period of time and the location of rainfall in the Municipality. The data was presented in Figure 1.

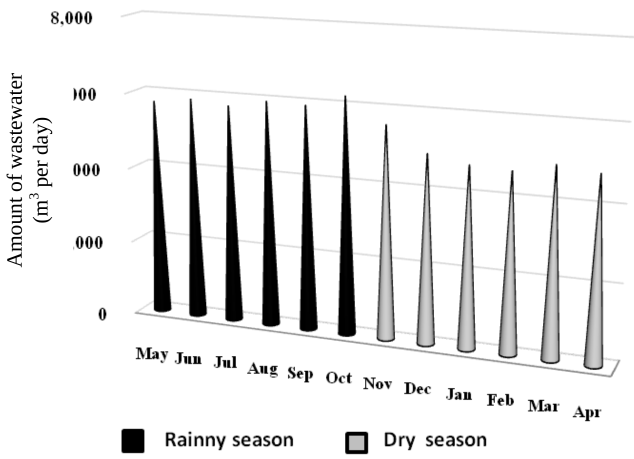


Figure 1 The monthly average amount of wastewater by season in Phetchaburi Municipality

3.1 The BOD loading over Phetchaburi Municipality

From the calculation to find the BOD loading over Phetchaburi Municipality during 2007 to 2012, it was found that the BOD loading tended to increase. The highest BOD loading was measured in October 2012 at 636.64 kg/day and the lowest BOD loading was measured in September 2008 at 42.32 kg/day. When classified by the rainy season to the dry season, the BOD loading during the rainy season was higher than that during the dry season. The average BOD loading of these two periods was 328.80 kg/day and 187.96 kg/day, respectively. It was also clearly with t-test that there was a statistical significant difference between these two values ($t = 3.410$, $p = 0.001$).

3.2 The representative of the BOD loading during the dry season

The distribution of the BOD loading data in the dry season classified by the rain-free duration was shown in Figure 2.

From Figure 2, it showed that the BOD loading increased when the rain-free duration was longer. The average values of the BOD loading in the rain-free duration of less than 30 days, 30-60 days and more than 60 days were 108.42 kg/day, 192.68 kg/day and 247.34 kg/day, respectively. Comparison was done over these 3 data by analysis of variance and $p = 0.004$ which meant that there was a significant difference. Moreover, when using Duncan's multiple range method to test the differences of each group of data, it resulted that the average value of the BOD loading for the less than 30 days of the rain-free duration was significantly different from those of the 30-60 and more than 60 days of the rain-free duration. While the average value of the BOD loading of the 30-60 days of the rain-free duration compared to that of the more than 60 days of the rain-free duration had no significant difference at 0.05 level. Thus, the estimate of the BOD loading during the dry season was equal to 208.29 kg/day for the more than 30 days of the rain-free duration with the highest and the lowest of the BOD loading at 274.81 kg/day and 111.96 kg/day, respectively. The standard deviation was at 57.89 kg/day.

3.3 The BOD loading during the rainy season when excluding the point source wastewater influence

Since the BOD loading during the rainy season was accumulated both from the buildings in the community source and the other source which was the non-point source wastewater. Then, the calculation to find the BOD loading from the non-point source wastewater pragmatically needed the BOD loading during the rainy season with exclusion of the influence of the BOD loading during the dry season which was equal to 208.29 kg/day. The result was the BOD loading during the rainy season excluding the point source influence as shown in Table 1.

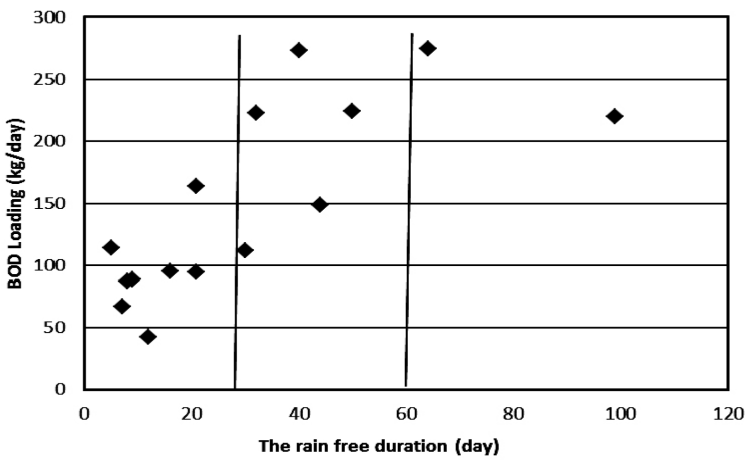


Figure 2 Comparison of the BOD loading during the 3 groups of rain-free duration

Table 1 BOD loading during the rainy season and BOD loading during the rainy season excluding the point source wastewater

Date	BOD loading during the rainy season (kg/day)	BOD loading during the rainy season excluding the point source wastewater (kg/day)
14 Jun 07	155.58	-52.71
12 Jul 07	155.80	-52.49
9 Aug 07	318.49	110.20
6 Sep 07	198.45	-9.84
11 Oct 07	125.95	-82.34
1 Jul 08	88.91	-119.38
4 Sep 08	42.34	-165.95
28 May 09	205.72	-2.57
24 Sep 09	248.94	40.65
29 Oct 09	259.66	51.37
27 May 10	317.87	109.58
24 Jun 10	435.04	226.75
22 Jul 10	413.59	205.30
26 Aug 10	455.11	246.82
23 Sep 10	546.96	338.67
28 Oct 10	315.30	107.01
25 Aug 11	563.44	355.15
22 Sep 11	492.47	284.18
23 Aug 12	417.06	208.77
27 Sep 12	511.56	303.27
25 Oct 12	636.64	428.35

3.4 The amount of storm water over each land use

The storm water over different areas would deliver the pollutants at the different amount depending on the area of the land use that rainfall had flowed through. The different land use areas had different runoff coefficient. Consequently, this study would divide the land use into two categories according to the land use pattern. The first category land use was for the construction building areas, i.e. the city areas, the official places, streets, residents and land fill with the runoff coefficient at 0.50-0.90. The second category of land use was for the natural and agricultural areas, i.e. forests, orchards and paddy fields, rivers and canals with the runoff coefficient at 0.03-0.30.

The land use patterns during the year 2007 to 2012 were compared, it can be concluded that most of the land use in Phetchaburi Municipality was in the first category. The land use in the first and the second category were 91.30% and 8.70% of the whole land use, respectively. There was also no changing in the land use pattern during this period of study as shown in Figure 3.

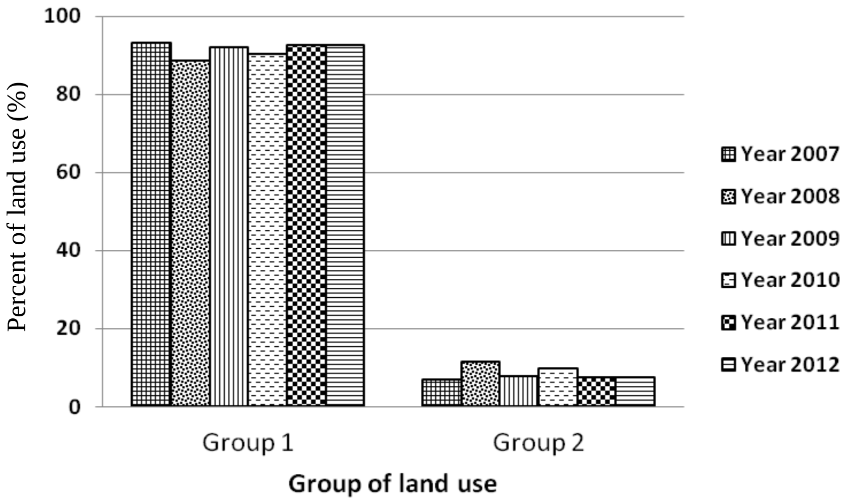


Figure 3 The percentage of the land use in Phetchaburi Municipality

Furthermore, the calculation had done to find the amount of the storm water over Phetchaburi Municipality during the rainy season. The result of the first category of the land use reached the highest point in September 2009 at 605.12 m^3/month or 20.17 m^3/day and fell down to the lowest point in May 2009 at 130.67 m^3/month or 4.22 m^3/day. While the result of the second category of land use reached the highest point in October 2010 at 11.40 m^3/month or 0.37 m^3/day and fell down to the lowest point in May 2009 at 2.36 m^3/month or 0.08 m^3/day.

3.5 The equation for the BOD loading estimation from the non-point source wastewater

The equation below was developed in the study of the BOD loading estimation from the non-point source wastewater (Y), by using the weighted least squares method. Here, the non-point source was divided into two groups; X_1 is the amount of rainfall over the non-point source of construction building areas and X_2 is the amount of rainfall over the non-point source of natural and agricultural areas.

$$\hat{Y} = 0.794X_1 - 25.455X_2 \qquad (1)$$

From the model, it was found that the BOD loading from the non-point source (Y) increased by 0.79 kg/day for every one cubic metre of the storm water from the first group (X_1). In contrast, it decreased by 25.45 kg/day for that from the second group (X_2). Besides, R^2 was analysed to be 0.362. The results of the regression coefficient test on the hypothesis H_0: $\beta_1 = \beta_2 = 0$ were shown in Table 2.

Table 2 Analysis of variance for the overall regression coefficient test

Source	Sum of squares	df	Mean of squares	F value
Regression	11.96	2	5.980	5.392
Residual	21.071	19	1.109	
Total	33.031	21	7.089	

As to Table 2, the value of calculated F was equal to 5.392 and it was compared to the value of F at the significance level 0.05 with the degree of freedom of $\nu_1 = 2$ and $\nu_2 = 19$, $F_{0.05,2,19}$ equals 3.52. Consequently, the value of the calculated F was found to be more than that of $F_{0.05,2,19}$ at the significance level (α) = 0.05. Therefore, the hypothesis test, H_0: $\beta_1 = \beta_2 = 0$ was to be rejected. In conclude, the overall regression coefficient was different as 0; $\beta_1 = \beta_2 \neq 0$.

The value of the calculated t of the hypothesis test H_0: $\beta_1 = 0$ equals 2.275 and the value of the calculated t of the hypothesis test H_0: $\beta_2 = 0$ equals -1.493 as shown in Table 3.

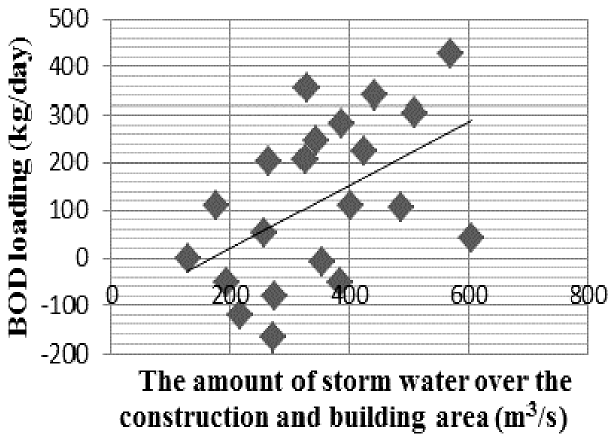
They were compared to the value of t at the significance level 0.10, $t_{0.10, 17}$ is 1.333. Consequently, the value of the calculated t for testing H_0: $\beta_1 = 0$ was found to be more than that of $t_{0.10, 17}$ which causes the main hypothesis that H_0: $\beta_1 = 0$ was to be rejected. For testing H_0: $\beta_2 = 0$, the absolute value of calculated t was more than that of $t_{0.10, 17}$, ($|t| = 1.493$). Therefore, the main hypothesis; H_0: $\beta_2 = 0$ was rejected. In conclude $\beta_1 \neq 0$ and $\beta_2 \neq 0$.

The coefficient of determination (R^2) in this study was 0.362 which means that the equation of the BOD loading estimation can estimate the BOD loading from the non-point source wastewater at 36.2 percent and the result of the sum of squared error was equal to 156.78.

The assumptions of the equation were proved. The graphs in Figure 4 show the linear relationship between the BOD loading from the non-point source wastewater (Y) and the amount of rainfall over the construction building areas (X_1) and the amount of rainfall over natural and agricultural areas (X_2), respectively.

Table 3 The calculated t value on each type of the non-point source for testing the hypotheses; H_0: $\beta_i = 0$; i = 1, 2

Source of the amount of storm water	β_i	Standard error (β_i)	Calculated t value
construction building areas (X_1)	0.794	0.349	2.275
natural and agricultural areas (X_2)	-25.455	17.041	-1.493



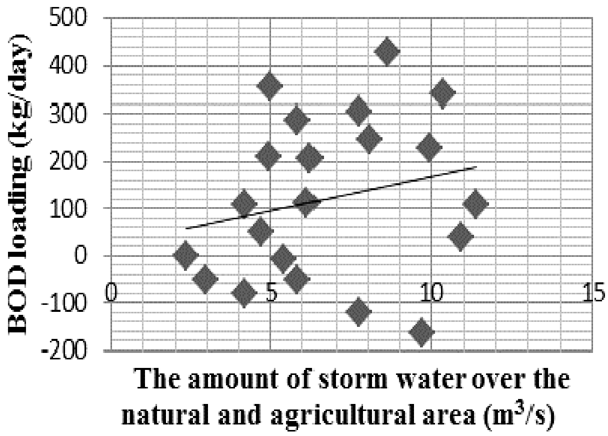


Figure 4 The relationship of the BOD loading from non-point source wastewater (Y) and the amount of rainfall over the construction building areas (X_1) and the amount of rainfall over natural and agricultural areas (X_2)

The result of the residual analyses was in between -1.5 and 1.5 as presented in standardized residual plot in Figure 5.

The result of the normality of error by normal plot was shown in Figure 6. It can be concluded that the error of the eqaution is a normal distribution.

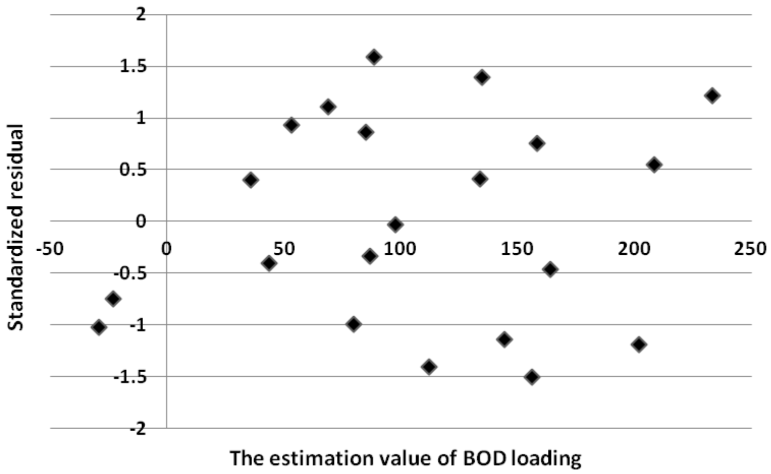


Figure 5 Scatter plot of the standardized residual and the estimation value of BOD loading

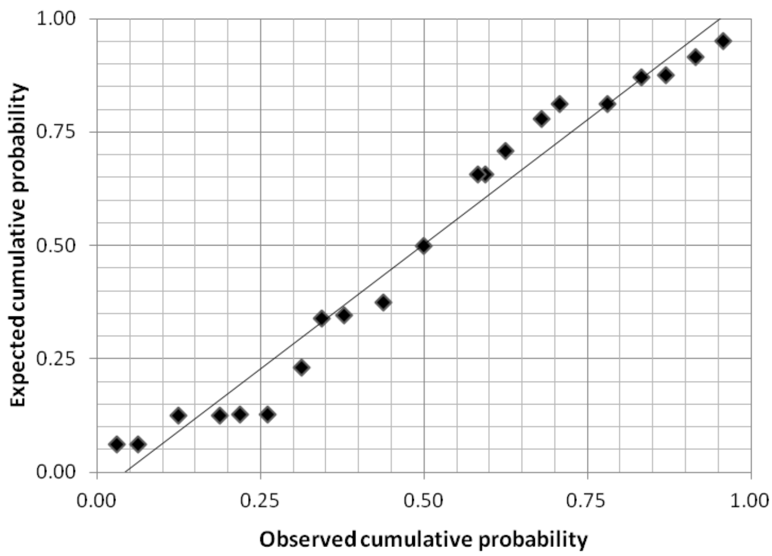


Figure 6 The normality assumption test of residuals

4. CONCLUSION

The average amounts of the BOD loading measured all over Phetchaburi Municipality during the rainy season and dry season were 328.80 kg/day and 187.96 kg/day, respectively. The amount of the BOD loading during the dry season with the rain-free duration of 30 to 60 days and that with the rain-free duration of more than 60 days had no difference. This means that the dirt washing up by rain caused the amount of the BOD loading was stable at the rain-free duration of 30 days and over. The estimated amount of the BOD loading during the dry season with the rain-free duration for more than 30 days was 208.29 kg/day. However, the BOD loading increased when the rain-free duration was longer because of no effect from the dilution process.

In this study, to calculate the amount of storm water over the land use of Phetchaburi Municipality, the area was divided into two categories by the land use and the runoff coeficient criteria. The first catagory was the construction building areas and the second category was the natural and agricultural areas. The ratio of the land use between these two categories was 10:1. However, the land use pattern from 2007 to 2012 had changed slightly. For the first category, the highest storm water quantity calculated was in September 2009 with 20.17 m^3/day and the lowest storm water quantity calculated was in May 2009 with 4.22 m^3/day. While for the second category, the highest storm water quantity calculated was in October 2010 with 0.37m^3 /day and the lowest storm water quantity calculated was in May 2009 with 0.076 m^3/day.

From the result of the study, it was found that the amount of the BOD loading from the non-point source wastewater had the positive relationship with the construction building areas while the negative relationship was found with the natural and agricultural areas. This can be concluded that the BOD loading could subside in the natural and agricultural areas because of the natural adaptation and land absorption. Therefore, this model can be applied to determine the suitable size of the green area zone in any urban area for the purpose of controlling the runoff BOD loading. The equation was developed according to the assumption of the regression equation and explained the studied variable at 36.2%. Nevertheless, owing to the lack of data needed in the study, the classification of the land use was limited. For the limitation of this model, this equation can be applied only the urban areas that classify the land use pattern into the construction building areas and the natural and agricultural areas. However, it cannot support the land use pattern which has more subdivided detail than this classification. For the recommendation for this study, the model capacity should be improved by increasing the data sets. The improved model would be expected to estimate the BOD loading for various types of land use pattern.

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