Impact of Pluvial First Flush – Application to Danang City, Vietnam

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Abstract. As cities in Vietnam, a combined drainage system has been building in Danang City. In recent years, Danang City has been extensively developing. However, additional wastewater treatment plants have not been built. As a result, wastewater and rainwater are discharged directly into the coastal areas. The initial period of the runoff after first rainfall events can be called the first flush, which has higher pollutants. So the contribution of pollutants from the first flush must be considered in order to correctly make an environmental preservation method for the coastal area. This study uses Mike Urban with modelling water quality to analysis the sensitivity of the NH₄⁺ concentration in the first flush of the areas. In addition, rainfall intensity and Antecedent Dry Weather Period are two key factors influencing the pollutants of the first flush. Through the results of the simulation, the NH₄⁺ concentration increase follows the rainfall intensity with maximum concentration appearing when rainfall intensity reaches 19 mm/h. However, NH₄⁺ concentration then decreases even when rainfall intensity increases. NH₄⁺ concentration reaches up to around 15 mg/l every 5 days dry period with 30 mm/h rainfall intensity.

1. Introduction

During dry weather, pollutants accumulate in urban catchments are produced mostly by human activity but also through atmospheric deposition. After a dry period, when rain appears, the first and fast contribution to runoff washes away impermeable surfaces, providing high concentrated pollutants in wastewater. Runoff on urban surfaces brings pollutants into drainage systems, including primarily settleable solids, nutrients, grease, oil, heavy metals, and bacteria. In recent times, the first flush phenomena are acknowledged as a typical phenomenon of highly populated and urbanized regions [1]. The first flush phenomenon can be described as the original rainwater runoff period during which pollutant concentration is significantly greater than in later stages [2]. Its impact varies according to the features of the sewer network and catchment [3]. This contaminated flow can be one of the main causes of stream quality deterioration if delivered through the drainage system outlet without treatment [1]. To properly implement an environment conservation technique for receiving water, the contribution of pollutants from the first flush must be assessed. Urban rainwater quality assessment is applicable to urban drainage, and mathematical models may be of excellent concern in this regard. To date, several comprehensive mathematical models have been accessible in urban drainage schemes to predict the quantity and quality of stormwater features [4].
Danang City is one of the largest port towns and the third-biggest city in Vietnam, with a 74 km-long shoreline located on the shore of the Eastern Sea [5]. Nowadays, urban drainage is one of the most significant environmental sustainability problems in highly anthropogenic fields [6]. In Vietnam, drainage systems are constructed with 92% general drainage network. They are primarily situated in the large towns and the coverage ratio is about 60% [7]. Similar to other cities in Vietnam, Danang City has a combined drainage system. Stormwater and wastewater are collected together in the same sewage network toward wastewater treatment plants before discharging into the natural environment such as rivers, lakes or coastal areas. A very small part of the new planning region has separated collection system. In recent years, Danang City has been developing rapidly, therefore, it is enlarged towards the North-West and South-East of the city. Unfortunately, wastewater treatment plants have not been built in these areas. As a result, the wastewaters from the drainage systems and stormwater are discharged directly into areas nearby the water environment, particularly on the coast of the East Sea and in the Danang Bay.

To simulate the water quality of the first flush, this research selected NH$_4$$^+$ for its as one of the typical pollutant parameters for water quality in stormwater [8] being thus one observed parameter of the National Technical Regulation on Marine Water Quality of Vietnam [9]. This study uses Mike Urban with a water quality module to analyse the sensitivity of pollutants in the first flush phenomenon of the areas in Danang City, Vietnam.

The sensitivity analysis was carried out to study the variation in the model output arising from distinct source changes in the model input [10]. Since a satisfying modelling practice needs modellers to assess model projections, sensitivity analysis should be prerequisite for modelling in any fields [11]. The first flush depends on several parameters, including imperviousness area, rainfall intensity, watershed area, and antecedent dry weather period [2]. Rainfall intensity and antecedent dry weather period are two key factors which influence the wash-off process of urban areas. In this study, sensitivity analysis is conducted on simulated pollutants peak concentration to determine the influences of two parameters discussed above.

2. Study area

![Map of Vietnam and Danang City](image1)

Figure 1. Study area

Danang City is the largest in the centre area of Vietnam, located along the coast of the East Sea at the mouth of the Han River. North-West (A) and South-East (B) areas of Danang City (Figure 1) have a low density of about 200 inhabitants/ha. Their drainage systems are quite simple with combined
wastewater and rainwater going directly to the sea since no wastewater treatment plants have been built there [12, 13]. In this study, we study the North-West area because the first flush phenomena directly discharge into Danang Bay and will affect the water quality of the coastal area. Its catchment area is 250 ha.

3. Material and methods

3.1. Model structure

The modelling software package for all urban water modelling operations is Mike Urban, which is run with the aid of Mike software from Danish Hydraulic Institute (DHI). In addition, Mike Urban covers all types of water networks, including stormwater drainage systems, water distribution systems, and sewage collection in both separate and combined systems. Mike Urban is used to model the collection system with the MOUSE engine. MOUSE is a strong and detailed engine for the modelling of complicated hydrology, sophisticated hydraulic systems in open and closed pipes, water quality and transport of sediments for urban drainage systems, sanitary sewers, and stormwater systems [14]. In this study, the model includes two major components. Firstly, the quantity module calculates the hydrographs at the outlet of the drainage system. Secondly, the quality module calculates the pollution graph simulation of different pollutants at the outlet of the drainage system.

3.1.1. Quantity module

The hydrodynamic model of the North-West area drainage system is a complete hydrodynamic sewer. MOUSE module is selected for hydrodynamic flow and water simulation in urban storm drainage and wastewater collection networks [14] which are combined in Danang City. The altitudes and lengths of drainage pipes are taken from regional construction planning. Then the drainage pipeline network is digitized through the ArcGIS function, and the corresponding node properties are achieved in the drainage system. Pipeline network topology relationship is verified to decrease the simulation mistake. The detail information and the data of pipeline nodes and drainage pipeline networks are supplied by the information database of Mike Urban model [15] (Figure 2).

![Figure 2. The drainage pipeline network of the study area](image)
In Mike Urban model system, the confluence node is laid at the centre of each sub-catchment. The sub-catchment division is based on the digitized outcomes of the study areas’ drainage pipeline network [16]. The combined drainage network has a total length of 11 km made of concrete pipes with a diameter ranging from 0.8 m to 1 m with 101 confluence nodes and 14 outlets. Therefore, the automatic division of sub-catchment results are checked and manually adjusted to the actual situation in order to improve the accuracy of the simulation [15].

3.1.2. Quality module

Some modules of MOUSE are available to simulate water quality for surfaces and drainage systems in urban catchments. First flush phenomena can only be simulated with a description of the sediment deposits temporally and spatially distributed on the catchment surface and in the drainage system [14]. MOUSE TRAP is based on the MOUSE package which is developed by DHI. In particular, MOUSE TRAP was created to determine the transport of sediments, dissolved, and sediment attached pollutants together with water quality processes in sewers pipe. There are 4 modules in MOUSE TRAP: Surface Runoff Quality (SRQ), Pipe Sediment Transport (ST), Pipe Advection-Dispersion (AD) and Biological Processes (BP). Only the SRQ module describes the transport processes on catchment surfaces, while other modules describe transport in pipes [17]. In this study, SRQ is used to calculate the concentration of NH$_4^+$ in first flush phenomena. The combination of SRQ and AD is used to calculate the quality water at the outlets along the beach.

According to the duration of the antecedent dry weather period, the mass of sediments accumulated in the surface catchments and sewers are calculated by the model. During the dry weather period, solids are accumulating established on the surface catchments and in sewer pipes. Antecedent dry weather period is counted days of less than 10 mm rainfall intensity [18].

SRQ module includes 3 sub-models that calculate: 1/ accumulation (build-up) and wash-off of particles on the catchment surface; 2/ the surface transport of pollutants attached to the sediments; 3/ build-up and wash-out of dissolved pollutants in gully pots [14].

3.2. Determination parameters of modelling water quality

The model’s prediction of water quality with the first flush phenomenon depends on adequate model parameter choice. However, accurate model parameters are difficult to determine and thus modelling results largely depends on this accuracy. Suitable values of build-up rate and wash-off exponent are needed before the models are used [19].

Unfortunately, little information is available on the pollutants of the first flush from urban areas in Vietnam. Therefore, in the present study, the concentration of pollutants at the outlets of the drainage network is assumed to be similar to Wuhan City, China, which also has a combined drainage system [18] and a similar climate.

In Wuhan City, rainfall intensity was 31 mm/h on 03/08/2005. Total nitrogen concentration peak at the outlet was 71 mg/l after an antecedent dry weather period of 15 days [18]. Therefore, this study assumes the NH$_4^+$ concentration peak at one outlet in Danang City will be around 71 mg/l when the rain appears 31 mm/h rainfall intensity after 15 dry days. Besides, the NH$_4^+$ concentration in wastewater is 25 mg/l during the dry season, which is taken from the data of the wastewater treatment plant in Danang City.

The calibration of the water quality model is required to determine the suitable pollutant model parameter values. Accordingly, the main parameter values of the build-up and wash-off model are adjusted constantly until the deviation between observed and simulated values is reduced to a satisfactory level [19].

3.3. Sensitivity analysis

The sensitivity analysis was carried out to study the variation in the model output obtained from distinct variation sources in the model input. To assess model projections, sensitivity analysis should be a prerequisite for modelling in any field [11]. The sensitivity analysis is carried out by changing each parameter while keeping other constants, after that observing changes in the output of the model [19].
The first flush phenomenon mainly depends on the following parameters: Antecedent dry weather period (ADWP), rainfall intensity, watershed area, imperviousness area [2]. Since the watershed area and imperviousness area are constant, the rainfall intensity and ADWP are two key factors that influence the first flush, especially, the build-up and wash-off process of the urban catchment surface. In this study, sensitivity analysis is conducted to determine the influence of the two parameters discussed above, on simulating peak concentration of NH$_4^+$ at the outlet. Firstly, changing the amount of ADWP and secondly, changing the rainfall intensity of each rain (table 1, 2).

| Events | ADWP (days) | Rainfall intensity (mm/h) |
|--------|-------------|--------------------------|
| 1      | 5           | 30                       |
| 2      | 10          | 30                       |
| 3      | 15          | 30                       |
| 4      | 20          | 30                       |

Table 1. Changing antecedent dry days

| Events | ADWP (days) | Rainfall intensity (mm/h) |
|--------|-------------|--------------------------|
| 1      | 15          | 15                       |
| 2      | 15          | 16                       |
| 3      | 15          | 17                       |
| 4      | 15          | 18                       |
| 5      | 15          | 19                       |
| 6      | 15          | 20                       |
| 7      | 15          | 21                       |
| 8      | 15          | 22                       |
| 9      | 15          | 23                       |
| 10     | 15          | 24                       |
| 11     | 15          | 25                       |

Table 2. Changing the rainfall intensity of each rain

4. Results and discussion

4.1. Calibration and parameters of water quality model

The calibration of the water quality model requires the estimation of the build-up rate and wash-off exponent parameters. Parameters obtained for the first flush phenomena in Wuhan City are used in this study. The first flush is simulated with a rainfall intensity of 31mm/h at 18:00. As a result, the value of parameters in the water quality model of the drainage network in Danang City is shown in table 3. Figure 3 shows the concentration of NH$_4^+$ at a given after a rainfall event.

| Descriptions | Range |
|--------------|-------|
| Build-up rate (kg/ha/day) | Pollutants accumulation rate on catchment surfaces | 0.21 |
| Max. build-up (kg/ha) | The threshold of pollutants build-up | 21 |
| ADWP (day) | Antecedent dry weather period | 15 |
| Detachment rate (m/h) | Detachment coefficient for rainfall | 0.001 |
| Wash-off exponent | Describe wash-off process | 2.0 |

Table 3. Parameters of the water quality model for Danang City
The results indicate that the NH$_4^+$ concentration peak is 70.32 mg/l. After that, the concentration of NH$_4^+$ goes down at a lower level than the initial concentration. Then, it returns to the initial value after 3 hours.

It appears reasonable for the NH$_4^+$ concentration to agree on the simulated results with the observed value for the estimated parameters. Due to the restriction of observed data, only one observation could be calibrated. In the future, more measured data will be needed to determine the model for Danang City. The input parameters in Danang City considerably differ from Mike Urban’s default values, which may not necessarily reflect local features. Therefore, the input parameters should be thoroughly chosen based on the features of the region.

4.2. Sensitivity analysis

4.2.1. Influence of antecedent dry days

The change in water quality is observed by calculating the NH$_4^+$ concentration with each value of the ADWP (table 1). Therefore, the accumulation pollutants according to time are built for 4 scenarios and the water quality of the first flush will be dominated by each value of ADWP. Figure 4 shows the results of the NH$_4^+$ concentration following the 4 scenarios.
From figure 4, it is clear that the value of the ADWP is the most sensitive parameter. With a 30 mm/h rainfall intensity, the NH$_4^+$ concentration increases of about 15 mg/l every 5 days dry period from 40 to 85 mg/l for the extreme scenarios of ADWP, 5 and 20 days, respectively.

4.2.2. Influence of rainfall intensity
The water quality adjustment is noted by calculating the concentration of NH$_4^+$ with each value of rainfall intensity. This study assesses the influence of the eleven values of rainfall intensity (table 2). Figure 5 shows the values of the NH$_4^+$ concentration peak depend on each value of rainfall intensity.

![Figure 5. Concentration of NH$_4^+$ at one outlet with eleven values of rainfall intensity](image)

Concentration of NH$_4^+$ increases up to a maximum for a rainfall intensity of 19 mm/h, with the value 75.64 mg/l (Figure 5). Beyond 19 mm/h, the NH$_4^+$ concentration decrease. On the whole, the concentration of NH$_4^+$ changes following rainfall intensity only increases remain in a narrow range of only 3%. In particular, the peak of NH$_4^+$ concentration are 73.03 mg/l, 73.62 mg/l, 74.29 mg/l, 74.95 mg/l, 75.64 mg/l, 75.01 mg/l, 74.68 mg/l, 74.15 mg/l, 73.57 mg/l, 73.25 mg/l, 72.86 mg/l respectively with rainfall intensity of 15 mm/h, 16 mm/h, 17 mm/h, 18 mm/h, 19 mm/h, 20 mm/h, 21 mm/h, 22 mm/h, 23 mm/h, 24 mm/h, 25 mm/h.

5. Conclusions
The aim of this study is to determinate the parameters of Modelling Water Quality in Danang City, Vietnam. The first flush phenomenon is calculated using NH$_4^+$ concentration. The parameters of the SRQ module in Danang City are significantly different from the default values in Mike Urban. Therefore, the input parameters should be carefully selected based on the characteristics of the region. Antecedent dry weather period (ADWP) and rainfall intensity are two main factors influencing of building the accumulation according to time and the urban wash-off process. In this research, a sensitivity analysis was performed to determine the effect of two mentioned above parameters on simulating the NH$_4^+$ concentration. With rainfall intensity of 30 mm/h, the concentration of NH$_4^+$ increases of approximately 15 mg/l every 5 dry days. The concentration of NH$_4^+$ peaks at 75.64 mg/l with a value of rainfall intensity 19 mm/h. According to the results of the sensitivity analysis, parameter of ADWP is the most sensitive in the water quality modelling results. Thus, estimating the build-up parameters is critical to ensure the precision of modelling outcomes for the water quality. This reality indicates that an advanced build-up and wash-off model’s generic implementation should be carried out with caution. Further study is required in order to derive adequate values of the build-up and wash-off model parameters with a higher degree of confidence for implementation in Danang region.

6. References
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