Methodology for Wastewater Discharge Modeling – Application to Danang Bay, Vietnam

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Abstract. The water quality of Danang Bay is one of the major issues on the coast of Danang City. The discharge will be inserted into this study domain through the outlet of the Phu Loc Channel. Mike 21 FM Hydrodynamics module coupled to a water quality model using Mike 21 FM ECOLab module is applied to simulate the water quality and to identify the spreading of \( \text{NH}_4^+ \), which is used as a pollutant tracer. Currently, the outlet of Phu Loc channel has a flow-directed wall which leads the water toward the centre of Danang city. As a result, the study suggests three scenarios of wastewater management from the outlet of Phu Loc channel. The first scenario is that the wastewater will discharge along with the current flow-directed wall. Second, the flow-directed wall will be reconstructed toward the reverse direction compared to the current direction. Third, the current flow-directed wall will be destroyed. Out of three proposed scenarios, the first one generates the longest polluted area toward the centre of the city, along the Danang Bay. Consequently, the current flow-directed wall is not the best way to discharge the wastewater of Phu Loc Channel. The finding of this research demonstrates that the best way to discharge the wastewater from Phu Loc channel would be a flow-directed wall reconstructed toward the reverse direction.

1. Introduction

With the growth of economic and natural science study capacity, more and more attention has been paid to water environment. Simulating water quality is one of the most important activities for the protection of water resources [1]. For the analysis of the coast’s affection and the ecological environment caused by the discharge of outlets along the coastal area. The two-dimensional hydrodynamic, mass transportation and diffusion models are applied individually to simulate the current field and the concentration of pollutants. Around the world, many coastal estuaries have been studied and numerical modelling is applied in water quality evaluation [2]. There is ample literature on the implementation of numerical models for assessing and controlling the quality and flow of water on the coast and estuaries [3]. The effects of wastewater discharge into surface waters are assessed using one, two, and three-dimensional water quality models [4]. Mathematical models are used to simulate the quality of water in reaction to modifications in surface water resources, supporting the evaluation of water pollution reduction technics [5].

Human settlements, industries, and agriculture are the three main sources of water pollution. Particularly, a number of issues arise when domestic wastewater is discharged into untreated water bodies and when heavy metals, solvents, poisonous sludge, and other wastes are discharged into water...
Danang Bay is located in the North-West area of Danang city. It is a bow-shaped coast with a 30 km-long coastline [7]. Especially, the outlet of Phu Loc channel connects with Danang Bay so the pollutants from Phu Loc channel directly go to the bay. On the other hand, Phu Loc channel is receiving many wastewater sources so that it has become the Danang Bay’s environmental hotspot. In this study, a hydrodynamic model using Mike 21 FM Hydrodynamics module coupled to a water quality model using Mike 21 FM ECOLab module is applied to simulate the water quality of Danang Bay and to identify the spreading of pollutants [8]. In particular, this study uses $\text{NH}_4^+$ to simulate the water quality of the coast in Danang Bay. The reason is that $\text{NH}_4^+$ is one of the typical water quality pollutant parameters of the National technical regulation on the coastal water quality of Vietnam. This study proposes three scenarios of wastewater diffusion from the outlet of Phu Loc channel. The first scenario is that wastewater will discharge along with the current flow-directed wall. In the second scenario, the flow-directed wall turns toward the reverse direction compared to the current direction. In the third scenario, the current flow-directed wall is destroyed. Then, this study will demonstrate the advantages and disadvantages of the three scenarios.

2. Study area

Danang City is Vietnam’s third-biggest city which is from $107^\circ 11'\text{ to } 108^\circ 20'$ longitudes and $15^\circ 15'\text{ to } 16^\circ 40'$ latitudes. It is located in the coastal area of the East Sea [Figure 1]. Furthermore, Danang is one of the most significant port cities in Vietnam. Danang Bay is situated in the North-West of the city. It displays a bow-shaped shoreline with a 30 km-long coastline [7].

The length of Phu Loc channel is around 2 km. Its outlet connects with Danang Bay which has 108.178 longitudes and 16.077 latitudes. The concentration of $\text{NH}_4^+$ in the wastewater of Phu Loc channel changes across time. Due to the different sources of urban wastewater. First, the leachate of Khanh Son landfill is not treated suitably according to standards. Second, wastewater from the slaughter area of Da Son poultry is untreated. Third, it is receiving from the outflow of Phu Loc wastewater treatment plant. In addition, the high population density of this area constantly increases. Hence, the wastewater overpasses the capacity of Phu Loc wastewater treatment plant. Consequently, some wastewater directly discharges into Phu Loc channel [9]. This study will simulate the water quality of Danang Bay which is affected by wastewater from Phu Loc channel. Presently, the outlet of Phu Loc channel is diverted toward the center of Danang city by a flow-directed wall (Figure 2).
3. Methodology

Modelling is a powerful tool to simulate the impact of watershed processes and water resource management. It can save time and money due to their ability to simulate the long-term effects of watershed processes and management activities on water quantity, water quality [10].

3.1. Modelling approach system

The model used in this study is MIKE 21 FM with the aid of DHI’s Mike software. MIKE 21 FM is a modelling based using an unstructured mesh. The modelling system was developed for oceanographic, coastal, and estuarine applications [11]. MIKE 21 FM consists of six modules. In this study, Mike 21 FM Hydrodynamics module is coupled to the water quality module Mike 21 FM ECOLab to simulate the water quality and to identify the diffusion of pollutants in the Danang Bay (Figure 3).

3.1.1. Hydrodynamic model

The hydrodynamic module is the fundamental computing element of the whole modelling scheme MIKE 21 FM. It provides the hydrodynamic foundation for the MIKE ECOLab module. The Hydrodynamic Module is based on the numerical solution of the averaged Navier-Stokes equations of the two-dimensional shallow water equations—the depth-integrated incompressible Reynolds [11]. The two-dimensional hydrodynamic model is used to simulate and calculate the sea level and water quality.
changes in estuaries and coastal regions. The model’s calculation grid is optimized to simulate the flow conditions to the best extent possible and to reduce calculation time. The finite element mesh technic created the flow module. The domains of computation are discreted by dividing domains into continuously non-overlapping grid cells [12].

3.1.2. Water quality model
MIKE ECO Lab module is an ecological modelling numerical laboratory. It is a generic instrument for designing water quality, heavy metal, ecology, and eutrophication used for environmental impact assessment [13]. Calculated hydrodynamic module findings enable the simulation of dynamic physical processes as the grounds for input into the MIKE ECO Lab module’s computational procedures [12]. ECO Lab simulates ecological parameters coupled offline with the forcing parameters generated in the hydrodynamic module. The water quality model and the hydrodynamic model are coupled through the transport equation [14]. The coupled models are used to simulate the spatial distribution of the variable concentration of pollutants along the coast. In this study, NH$_4^+$ was chosen because it is one parameter of the National technical regulation for coastal water quality of Vietnam [15].

3.2. Model setup
The domain is set up over an area of about 5000 km$^2$ (70 x 70 km), wide enough to minimize the impact of uncertainties on the main study area in open boundaries [16]. To generate the computational mesh, the modelling domain is divided into components. We use a non-structured mesh size with triangular components, performed with Delaunay triangulation [17]. The non-structured mesh is generated with Mike Zero Mesh Generator providing a domain of 12870 elements and 7240 nodes (Figure 4). Grids near the shore are denser than that offshore (max 1000 m), with a denser mesh at the outlet of Phu Loc channel (min 15 m). The per-hourly water level is prescribed along the open boundary. Tide is determined using the height tide forecast toolbox in the 2D model [18] using water levels from the prediction based on global tide model data for boundaries 10, 20, 30 [19]. Boundary 40 and 50 are specified levels in Hoi An and Cam Le rivers stations. Finally, boundary 60 is specified discharge from Phu Loc Channel which is assumed to be similar to the flow discharge from Phu Loc wastewater treatment plant (0.5 m$^3$/s).

![Image](image_url)

**Figure 4.** Unstructured mesh produced for the offshore domain

Presently, the outlet of Phu Loc channel has a flow-directed wall that leads the water toward the center of Danang city. Three scenarios of the outlet of Phu Loc channel are studied. The first scenario is that wastewater discharges along with the current flow-directed wall (Figure 5a). Second, the flow-directed wall turn in the reverse (Figure 5b). Third, without any flow-directed wall (Figure 5c).
Figure 5. The three scenarios for the structures of the Phu Loc channel’s outlet. Frame a corresponds to the current situation, b and c are additional scenarios.

Bathymetric data is shown in Figure 6. The greatest depth is 140 m. The models’ input parameters include the six boundary conditions, wind direction, wind speed, bathymetry, and the data of water quality parameters. The wind direction and speed data are from the Son Tra station (16.116 N, 108.225 E). The model is simulated in March 2017 for thirty days (21,600 time steps with an interval of 120s). The calculation time step for one simulation is approximately 4h.

Figure 6. Bathymetry of the domain
NH\textsubscript{4}\textsuperscript{+} concentration in the wastewater of Phu Loc channel is assumed 20 mg/l. This value is assumed to be constant. Accordingly, it is used to simulate the effect of wastewater from Phu Loc channel to the water quality in the coastal area of Danang Bay.

3.3. Model assessment
The performance of the model is evaluated using the coefficient of determination (R\textsuperscript{2}), Nash Sutcliffe efficiency (NSE), and percent bias (PBIAS) [20]. R\textsuperscript{2} predicts future results on the basis of other associated data [21]. NSE is a standardized statistic determining the relative scale of the variance excess compared to the observed variance [22]. PBIAS measures the simulated data’s average tendency versus the observed counterparts [23]. Values < ±10% are considered as very good [24].

4. Results

4.1. Validation of the hydrodynamic model
The hydrodynamics model validation is performed by comparison of the water elevation from observed data and simulation results at the Son Tra station. The model is initially validated with the water level tide data from 5\textsuperscript{th} to 17\textsuperscript{th} February 2017. The result of the validation model for sea surface elevation at Son Tra gauge station is shown in Figure 7.

Model results match with observation data within water level difference of maximum 10 cm. Besides, the Nash-Sutcliffe efficiency (NSE) value in the validation process is 0.92. The value of the coefficient of determination (R\textsuperscript{2}) is 0.92. Percent bias (PBIAS) values for validation is -8.2%. Validation results demonstrate that the model produced a good simulation that can be used to simulate the water quality.

4.2. The water quality of Danang Bay
The simulation model and the results of the three scenarios are observed on 02/03/2017 16:00 (Figure 8).
- Scenario a (with current flow-directed wall): NH\textsubscript{4}\textsuperscript{+} covers an area 0.5 km wide along the coastline with concentration > 0.5 mg/l. At that moment, an area of 0.1 km\textsuperscript{2} is covered by 0.25-0.5 mg/l NH\textsubscript{4}\textsuperscript{+}. In addition, there are several periods of a short time when the long-polluted area toward the center of the city covers an area of around 1 km\textsuperscript{2}. 

![Figure 7: Validation of water level at Son Tra station using Feb. 2017 observed data](image-url)
- Scenario b (with the reverse direction of the wall): NH$_4^+$ concentration is over 0.5 mg/l in the coastal area toward the West of the city with an area of around 0.5 km$^2$. The polluted area along the coast is shorter than scenario a, it is around 0.5 km. However, the NH$_4^+$ distribution is larger toward an offshore direction.

- Scenario c (without flow-directed wall): NH$_4^+$ concentration > 0.5mg/l is located near the outlet of Phu Loc channel, cover approximately 0.6 km$^2$. The polluted area along the coast is longer than in scenario a and b.

On the whole, the outlet of Phu Loc Channel generates coastal water concentration of NH$_4^+$ higher than the limited standard of Vietnam regulation (0.5 mg/l). The three scenarios of outlet cause various polluted areas. Out of three scenarios, the first one having the current flow-directed wall generates the longest polluted area along the Danang Bay toward the center of the city. Moreover, the third one (without wall structure) has the longest polluted area along the coast. Consequently, the current flow-directed wall is not the best way to discharge the wastewater of Phu Loc Channel. Therefore, this study suggests that the best way to discharge wastewater of Phu Loc channel would be scenario b with a flow-directed wall reconstructed toward the reverse direction.

![Figure 8](image_url)

**Figure 8**: The calculation results of the NH$_4^+$ concentration of water quality for scenarios (a, b, c)

### 5. Conclusions

Using water quality models in coastal areas can be helpful tools to assess water quality. The present study describes the application of coupled hydraulic and water quality models to assess the dispersion of pollutants in the coastal area of Danang Bay. Mike 21 FM Hydrodynamics and ECOLab modules are combined to simulate the water quality and the dispersion of NH$_4^+$. Observed tide water level is used for validation. Finally, the validation results demonstrate that the model produced good simulation, with satisfactory values of $R^2$ (0.92), NSE (0.92), PBIAS (-8.2%). Presently, the outlet of Phu Loc channel has a flow-directed wall that leads the water toward the center of Danang city. This study proposes three scenarios of wastewater discharge from the outlet of Phu Loc channel using observed data in March 2017. Results indicate that the discharge outlet of Phu Loc Channel generates a concentration of NH$_4^+$ in coastal water of Danang Bay higher than the limited standard of Vietnam regulation. Scenario a, with the present flow-directed wall, produced the longest polluted area toward the center of the city. Scenario c has the longest coastal longest pollution. The present flow-directed
wall is therefore not the best way to discharge Phu Loc channel’s wastewater. Thus, this research suggests that the less impacting way to discharge wastewater from Phu Loc channel would be scenario b, with a reconstruction of the flow-directed wall in a direction opposite to the present one. This study could also be used as a reference for prediction and protection for the water quality in Danang Bay. Future research needs to explore the effect of waste sources on the coastal area of Danang Bay.

6. References

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