Optimization of Channel Outlet in the Coastal Area — Application to Da Nang Bay, Viet Nam

Phuoc Quy An Nguyen, Philippe Gourbesville, Philippe Audra, Ngoc Duong Vo, and Diep Ngoc Khoi Vo

***Abstract*—The water quality of Da Nang Bay (Viet Nam) is one of the major issues on Da Nang City's coast. The discharge of the Phu Loc (PL) channel will be inserted through the outlet into Da Nang Bay. However, the PL channel receives many sources of wastewater so the highly polluted channel water. Therefore, the outlet of PL channel has become the environmental hotspot of the Da Nang Sea. Mike 21 FM Hydrodynamics module coupled with a water quality model using Mike 21 FM ECOLab module is used to simulate water quality and to identify the spreading of NH_4^+, which is used as a pollutant tracer. Currently, the outlet of PL channel generates the polluted area along the coast in different directions depending on the current and the direction of the wind. This study proposes three scenarios of designing the outlet far from the coastline 400 m, 500 m, and 600 m, respectively. The finding of this research demonstrates that the best way to discharge the wastewater from PL channel would be the outlet to be moved 500 m away from the coastline. NH_4^+ concentration > 0.2 mg/l will cover an area that distributes about 100 m around the coastline. NH_4^+ concentration > 0.5 mg/l covers an area approximately 0.03 km^2.**

***Index Terms*—Coast, Da Nang Bay, PL channel, MIKE 21 FM ECOLab.**

I. Introduction

With the growth of capacity for studying economic and natural science, more and more attention has been paid to the environment of water. Water quality simulation is one of the most important activities for water resource protection [1]. The discharge of outlets along the coastal area affects the coast and the ecological environment. To simulate the current field and pollutant concentration, the two-dimensional hydrodynamic, mass transportation, and diffusion models are applied individually. Many coastal estuaries have been studied around the world and numerical modelling is applied in the assessment of water quality [2]. There has been ample research on the implementation of numerical models for evaluating and managing coastal and estuary water quality and flow [3]. The effects of sewage discharge into surface water are measured using one, two, and three-dimensional models of water quality [4]. Mathematical models are used to predict water quality in response to changes in surface water supplies and to help water pollution management techniques [5]. The three main sources of water pollution are human communities, factories, and agriculture. Especially when untreated domestic wastewater is discharged into water bodies and when heavy metals, solvents, toxic sludge, and other wastes are discharged into receiving water bodies [6].

Da Nang Bay is located in Da Nang City's North-West area. It is an arch-shaped coastline with a coastline of 30 km. In particular, the PL channel outlet interacts with Da Nang Bay so that the PL channel contaminants go directly to the bay. On the other hand, the PL channel receives many sources of wastewater so the highly polluted channel water. Thus, dead fish often occur on the PL channel, especially in the hot season. Therefore, the outlet of PL channel has become the environmental hotspot of the Da Nang Sea.

In this study, a hydrodynamic model using the Mike 21 FM Hydrodynamics module combined with a water quality model using the Mike 21 FM ECOLab module is used to simulate Da Nang Bay's water quality and to identify pollutant spread [7]. Particularly, this study uses NH_4^+ to model the coastal water quality in Da Nang Bay. The reason is that NH_4^+ is one of the typical polluting water quality parameters of Viet Nam's National Technical Regulation on Coastal Water Quality. This study suggests three scenarios of PL channel's outlet to reduce the effect on the coast of Da Nang Bay. The scenarios study the effect of the moving of the channel outlet far from the coastline and will assess the best way to discharge the wastewater.

II. Study Area

Da Nang City ($107^0$17' to $108^0$20' longitudes and $15^0$15' to $16^0$40' latitudes) is the third biggest city of Viet Nam (population 1.215.000), and one of the most important port cities. It is located in the East Sea coastal area (Fig. 1). Da Nang Bay is located in the North-West of the city. It displays a bow-shaped 30 km-long coastline.

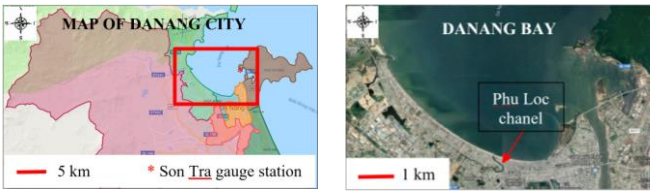

Fig. 1. Study area.

The PL channel's length is about 2 km long. The concentration of NH_4^+ in the PL channel wastewater changes over time according to different urban wastewater sources. First, Khanh Son landfill leachate (W1) is not treated as per requirements. Second, there is no treatment of wastewater from the Da Son poultry slaughter zone (W2). Third, it

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receives the outflow of a wastewater treatment plant (W3). Moreover, the high population density is constantly increasing in this area. Consequently, the wastewater exceeds the capacity of the Phu Loc wastewater treatment plant, and some wastewater discharges directly into the PL channel. This study would model Da Nang Bay's water quality that is affected by PL channel wastewater. The outlet of the PL channel is currently being diverted by a flow-directed wall to the center of Da Nang City. We will study three scenarios for moving the outlet of PL channel far from the coastline, at 400 m (S1), 500 m (S2), and 600 m (S3).

III. Methodology

Modelling is a powerful tool for simulating the effect of water resource management and ecosystem processes. It could save money and time because of its ability to predict the long-term effects on water volume, the water quality of water processes and management activities [8].

A. Modelling Approach System

MIKE 21 FM is the model used in this study with the aid of Mike software from Danish Hydraulic Institute (DHI). MIKE 21 FM is unstructured mesh-based modelling. The modelling system was developed for applications in oceanography, coastal and estuarine [9]. MIKE 21 FM has six modules. In this study, the Mike 21 FM Hydrodynamics module is combined with the Mike 21 FM ECOLab water quality module to simulate the water quality and identify pollutant diffusion in the Da Nang Bay (Fig. 2).

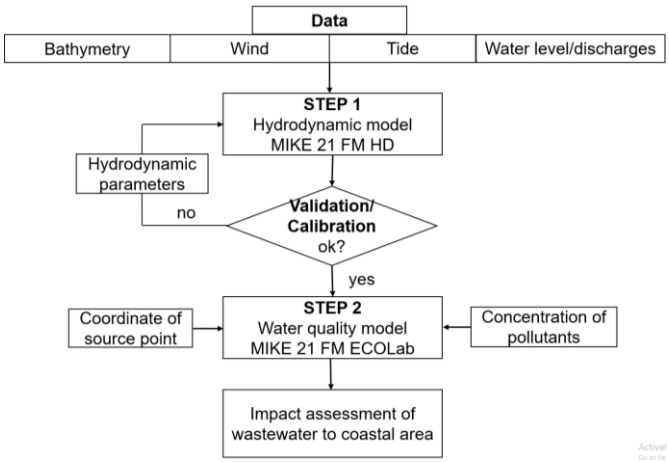

Fig. 2. Description of the approach applied.

B. Hydrodynamic Model (HD)

The hydrodynamic module is the basic computing element of the entire MIKE 21 FM modeling scheme. It provides the MIKE ECOLab module with the hydrodynamic foundation. The Hydrodynamic model is based on the mathematical solution of the averaged Navier-Stokes equations of the two-dimensional shallow water equations-the depth-integrated incompressible Reynolds [9]. The hydrodynamic two-dimensional model is used to simulate and calculate changes in sea level and water quality in coastal regions and estuaries. The calculation grid of the model is designed to simulate the flow conditions as far as possible and to reduce the calculation time. The flow module was created by the finite element mesh technique. The computing domains are divided into continually non-overlapping grid cells [10].

C. Water Quality Model (WQ)

MIKE ECO Lab module is a computational platform for ecological modeling. It is a common method used for environmental impact assessment to model water quality, ecology heavy metal, and eutrophication [11]. Calculated findings of the hydrodynamic module allow the simulation of dynamic physical processes as the basis for input into the computational procedures of the MIKE ECO Lab module [10]. ECO Lab simulates the ecological parameters of the hydrodynamic module coupled offline with the forcing parameters. The water quality model is coupled with the hydrodynamic model through the transport equation [12]. Coupled models are used to simulate the spatial distribution of the concentration of pollutants along the coast. NH_4^+ was selected in this study because it is a parameter of Viet Nam's National Technical Regulation on Coastal Water Quality [13].

D. Model Setup

The domain is set up over an area of approximately 5,000 km^2 (70 × 70 km), large enough to minimize the impact of uncertainties in open boundaries on the main study area [14]. The modeling domain is divided into components in order to generate the computational mesh. With Delaunay triangulation, we use a non-structured mesh scale with triangular components [15]. The non-structured mesh is generated with a domain of 12,870 elements and 7,240 nodes provided by Mike Zero Mesh Generator (Fig. 3). The grids near the shore are denser (min. 15 m at the outlet of the PL channel), than offshore (max. 1.000 m). The water level per hour is indicated along the open boundary. Tide is estimated using the 2D model's height tide forecasting toolbox [16] using global tide model estimation water levels for boundaries 10, 20, 30 [17]. At Hoi An and Cam Le rivers stations, boundaries 40 and 50 are defined. Lastly, the PL channel boundary 60 discharge is specified, which is presumed to be close to the Phu Loc wastewater treatment plant stream discharge (0.5 m^3/s).

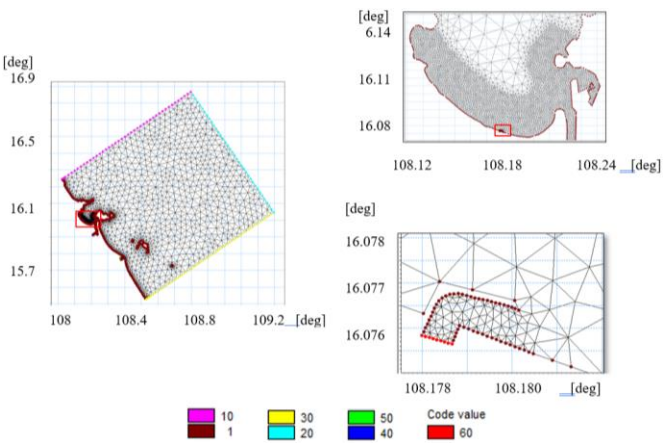

Fig. 3. Unstructured mesh produced for the offshore domain.

Fig. 4 shows the bathymetric data. The maximum depth is 140 m. The input parameters of the models include: six boundary conditions, wind direction, wind speed, bathymetry,

and parameter data for water quality. Wind direction and speed data are collected from the Son Tra station (16.116 N, 108.225 E). The model will be simulated for thirty days in March 2017 (21,600-time steps with a 120s interval). For one simulation, the calculation time step is approximately 4h.

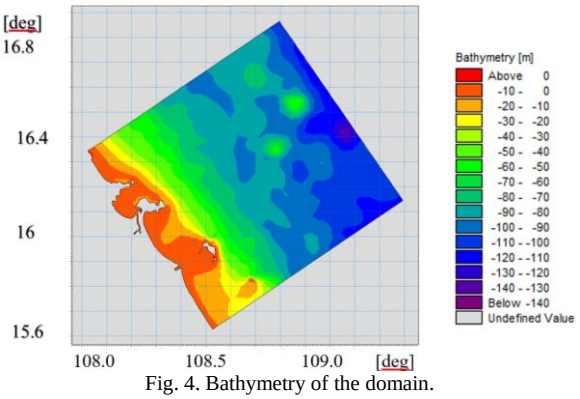

Fig. 4. Bathymetry of the domain.

NH_4^+ average concentration input in WWTP is 25 mg/l before treatment (data Phu Loc WWTP). In the outlet of Phu Loc WWTP, the concentration of NH_4^+ is 15 mg/l. In this study, the concentration of NH_4^+ in PL channel wastewater is assumed to be 20 mg/l and constant.

E. Model Assessment

The model's output is evaluated using the efficiency of Nash Sutcliffe (NSE), the correlation coefficient (R), and the root mean squared error (RMSE). NSE is a standardized statistic that specifies the relative scale of the excess variance compared to the variance observed [18]. R is used to investigate the level of linearity between simulated and observed data. RMSE is the square root of the mean square error (MSE), and in regression analysis, the MSE is also known as the standard estimate error. The lower RMSE value, the higher performance of the model will be achieved [19]. The value of NSE and R are considered to be good when $0.85 \leq R \leq 1$; $0.65 \leq NSE \leq 1$ [20].

IV. Results

A. Validation of the Hydrodynamic Model

The validation of the hydrodynamics model is performed out by comparing the water elevation from observed data and the results of simulation at the Son Tra station. The model is effectively validated from 5th to 17th February 2017 with water level tide data. Fig. 5 shows the outcome of the sea surface elevation validation method at Son Tra gauge station.

Model results match observation data of a maximum of 10 m difference in water level. In addition, in the validation process, the Nash-Sutcliffe efficiency (NSE) value is 0.92. The correlation coefficient (R) is 0.97. The root mean squared error (RMSE) is 0.057. The results of the validation show that the model produced a good simulation that can be used to simulate the quality of the water.

B. Current Water Quality of Da Nang Bay

Description of the PL channel's outlet discharge into the coast is shown in Figure. 6 for simulation results. Results of the NH_4^+concentration calculation, are observed at 23:00 27/03/2017, 16:00 07/03/2017 and 15:00 05/03/2017, respectively (Fig. 6). NH_4^+ covers an area that spread to Da Nang Bay around the outlet. The polluted areas spread along the coast with a different direction, depending on the wind direction and the current in the study domain. NH_4^+ concentration > 0.2 mg/l is located near the outlet of PL channel from 1.3 – 1.6 km along the coastline of Da Nang Bay. NH_4^+ concentration over 0.5 mg/l covers an area of around 0.3 km^2.

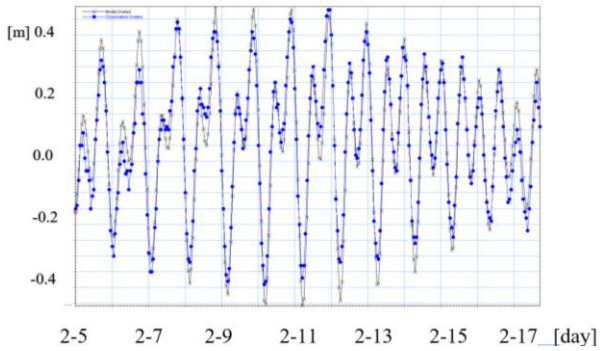

Fig. 5. Validation of marine surface level at Son Tra station using Feb 2017 observed data.

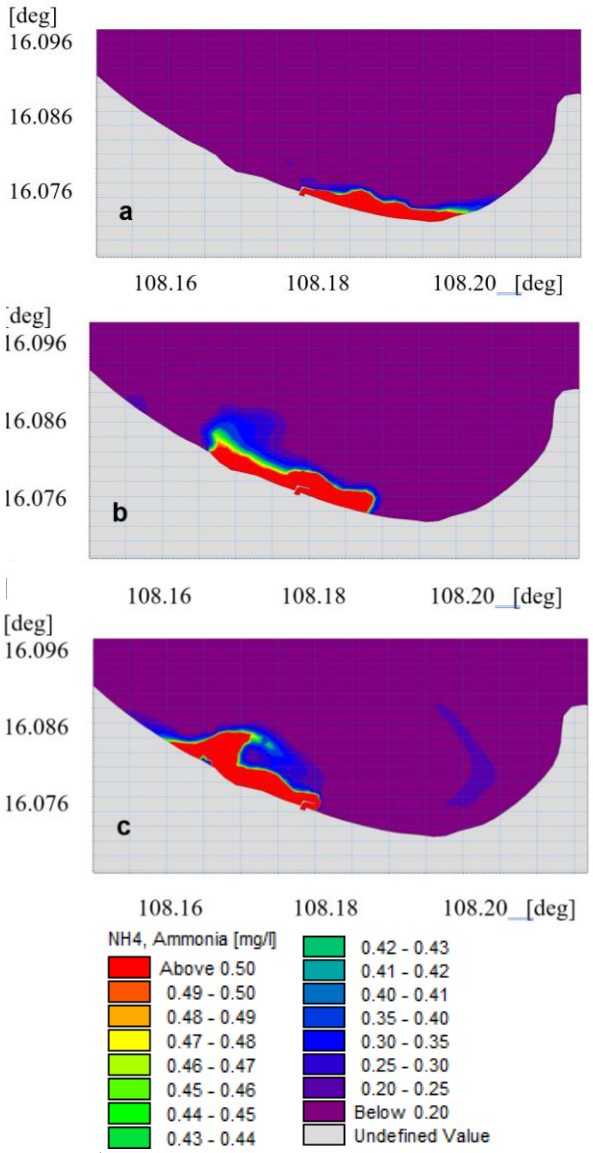

Fig. 6. NH_4^+ concentration with the current outlet of PL channel for 3 observations.

C. A Solution for the Outlet of PL Channel

The study suggests three scenarios to reduce the effect of PL channel's outlet on the coast of Da Nang Bay. The simulation model and the results of the scenarios are observed on 10/03/2017 10:00 (Fig. 7).

- S1 (outlet 400 m offshore): normally, NH_4^+ concentration > 0.5 mg/l covers an area that distributes about 100 m from the coastline. However, sometime the NH_4^+ distribution spreads near the shore. At that moment, an area of 0.15 km2 is covered by NH_4^+ concentration > 0.5 mg/l.
- S2 (outlet 500 m offshore): NH_4^+ concentration > 0.5 mg/l covers an area that is smaller than scenario 1, approximately 0.03 km2. At around 100 m from coastline, NH_4^+ concentration is > 0.2 mg/l.
- S3 (outlet 600 m offshore): NH_4^+ concentration > 0.5 mg/l is located farther from the coastline, around 200 m, and covers approximately 0.02 km^2. The polluted area with NH_4^+ concentration > 0.2 mg/l is far around 100 m from the coastline.

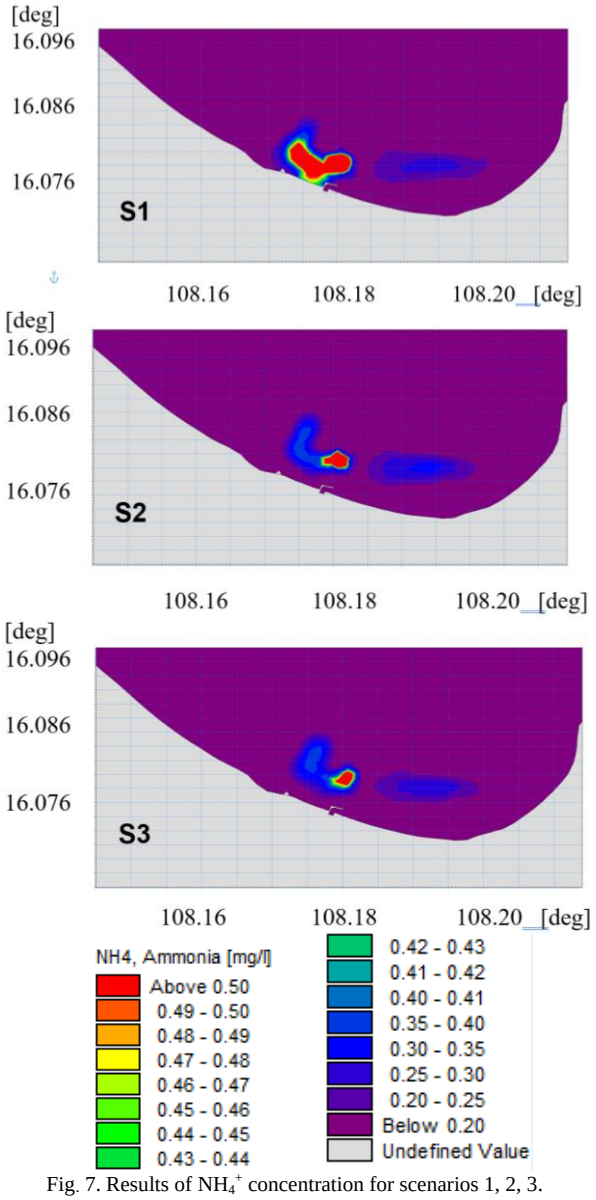

Fig. 7. Results of NH_4^+ concentration for scenarios 1, 2, 3.

On the whole, the PL channel's outlet produces a higher coastal water concentration of NH_4^+ than the limited standard of Viet Nam regulation when moving the outlet far from the coastline. The three outlet scenarios cause different polluted areas. Out of three scenarios, the first one with the outlet locating 400 m from the coastline generates the largest polluted area, and NH_4^+ concentration > 0.5 mg/l is located closer to the coastline than with another scenario. Scenarios 2 generates a similar polluted area than scenario 3. In scenario 2, NH_4^+ concentration > 0.5 mg/l covers an area that is of similar size than for scenario 3 (+0.01 km^2). In addition, NH_4^+ distribution located far from the coastline around 100 m with NH_4^+ concentration > 0.2 mg/l, and 200 m with NH_4^+ concentration > 0.5 mg/l. Thus, the study suggests that the best way to discharge wastewater of PL channel would be scenario 2 with moving the outlet 500 m away from the coastline.

V. Conclusions

Presently, the outlet of PL channel directly connects with Da Nang Bay. Therefore, it generates a polluted area along the coast with different directions depending on the current and the wind direction.

NH_4^+ concentration > 0.2 mg/l is located near the PL channel outlet around 1.3-1.6 km along the Da Nang Bay coastline, and the area with concentration > 0.5 mg/l is approximately 0.3 km^2. This study proposes three scenarios of moving the outlet far from the coastline, at 400 m, 500 m, and 600 m, to provide a solution to limit the pollution from the outlet of PL channel. Results indicate that the outlet should be moved 500 m away from coastline. NH_4^+ concentration > 0.2 mg/l would cover an area around 100 m away from the coastline. And NH_4^+ concentration > 0.5 mg/l would cover an area of approximately 0.03 km^2.

This research describes the use of combined hydraulic and water quality models to determine pollutant dispersion in Da Nang Bay's coastal area. The modules Mike 21 FM Hydrodynamics and ECOLab were combined to simulate water quality and NH_4^+ dispersion. For validation, the observed tide water level was used. Lastly, the results of the validation have shown that the model provided successful simulation with satisfactory values of NSE (0.92), R (0.97), and RMSE (0.057). Such models can be useful tools for assessing water quality in coastal areas.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nguyen Phuoc Quy An conducted the research and wrote paper; Diep Ngoc Khoi Vo and Ngoc Duong Vo collected data, Philippe Gourbesville and Philippe Audra checked all paper; ...; all authors had approved the final version.

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