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Assessment of water quality variations due to operation of wastewater treatment plant in Ca Mau city

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ABSTRACT

The wastewater treatment plant (WWTP) in Ca Mau city, which is being planned for construction, will be responsible for treating domestic wastewater with a capacity of 8,000 m^3/day. After being treated by the physic-biological method, the plant's wastewater will be discharged into the Thong Nhat canal and the Tac Thu river. As a result, this article applies the MIKE 21 model to calculate the range, the distance, and the concentration of typical pollutants for domestic wastewater, including TSS, BOD_5, NH_4^+, and total Coliforms in the dry season, to provide evidence for water resource management following the plant's construction. Two scenarios were established; in scenario 1 (*S*1), the WWTP is being operated inefficiently, and the wastewater has not been treated up to standards. Maximum calculation in case the processing performance = 0; in scenario 2 (*S*2), the WWTP is being operated efficiently. The concentration of 4 components in wastewater is lower than the critical value of QCVN 14:2008/BTNMT (column *B*, *K* = 1). The results show that the waste source will highly affect the water in the Thong Nhat canal both downstream and upstream due to the irregular semi-diurnal tide regime in case of the plant experiences problems (*S*1). In the case of the stable operation plant (*S*2), the pollutant concentrations at all positions will be lower than the critical value of QCVN 08-MT:2015/BTNMT (column *B*1) except for the TSS. Concentration variation is evident over time and distance: after about 1 hour and about 1 km from the source, the concentration of pollutants reaches the maximum value, then gradually decreases and ends at about 4 km after 7 hours.

Keywords: Domestic wastewater, pollutant, wastewater treatment plant, modelling MIKE 21, Ca Mau city.

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INTRODUCTION

Despite being the political, economic, cultural, commercial, and service center of Ca Mau province, Ca Mau city, on the other hand, does not have an integrated wastewater treatment plant. Wastewater, not being treated completely, is currently discharged altogether with the rainwater drainage system into ponds, lakes, and canals. This practice has been polluting the environment and affecting social-economic development and people's health. In 2020, the Prime Minister of Vietnam issued Decision No. 480/QĐ-TTg to approve the project of "*Renovating and building the drainage and wastewater treatment system in Ca Mau city (phase 1)*". The purpose is to build a drainage system for both rainwater and wastewater and a wastewater treatment plant with a capacity of 8,000 m^3/day. The plant applies aerobic biological (aero tank) and physical treatment methods. The treated wastewater will be discharged into the Thong Nhat canal and then will lead to Tac Thu river, which meets QCVN 14:2008/BTNMT - National Technical Regulation on domestic wastewater (column B).

Nevertheless, Ca Mau city has a dense river system and is the convergence of manay main rivers, connecting the East Vietnam Sea and Thailand bay. The construction of a domestic wastewater treatment plant with a large capacity in the city will put pressure on the regional river system. Therefore, considering the distance and the concentration of pollutants in the wastewater is the basis of assessing the range and impact level of the discharge process to take appropriate mitigation measures.

Several models have been applied in wastewater dispersion simulation, such as QUAL2K (or Q2K), DELFT 3D, and MIKE, all of which obtained favorable results in forecasting work in the early stages [1–8]. In this article, the MIKE model - software of the Danish Hydraulic Institute, has been selected to apply in the calculation of hydraulics and resources - environment, including rivers, estuaries, and coastal areas, and the sea. Even though the MIKE model has been applied with consideration of the tidal regime by many previous researchers, most of its applications were carried out in large river basins with long time-series hydrological data [9]. The application of the MIKE model is relatively diverse, being related to sea river dynamics, oil spills, turbidity, and some main pollution parameters in domestic wastewater [10].

The purpose of renovating and upgrading the water drainage system is to collect waste sources for treatment to deal with environmental pollution. Nevertheless, a large amount of wastewater at 8,000 m^3/day will pressure the receiving sources, namely the Thong Nhat canal and Tac Thu river, especially when plant encounters problems and the wastewater is not treated thoroughly. Therefore, the results of this article are the scientific and practical basis for the operation of the wastewater treatment system and management of the output water quality. This article is also the scientific basis for management agencies to determine the scope of influence and pollution level of the plant if operated.

METHODOLY AND INPUT DATA

In the field of environmental hydrology, there are many ways to approach the problem. There are many ways, models, and techniques to assess pollution levels. This article uses an integrated approach; based on the analysis of wastewater treatment technology and the provisions of the law on environmental protection, the paper develops a typical case for the wastewater treatment plant. Among the above models, MIKE 21 is a 2D hydraulic model which includes the following modules: Hydrodynamic (HD), Transport (TR), Eco Lab (EL), Mud Transport (MT), Sand Transport (ST) and has been used to simulate hydraulic processes as well as environmental phenomena in estuaries, bays, inshore and coastal areas. The study uses different data sources on hydrological conditions and natural and socio-economic conditions to select a simulation model for transmission. Wastewater from the Plant, under the influence of flow, wave, wind, tidal regime, etc., will diffuse and spread pollutant compounds. Therefore, the dynamic process plays an essential role in wastewater distribution, transmission, and dilution. In forecasting, the modeling method is a common way. MIKE software contains of a few modules such as MIKE Zero, MIKE 11, MIKE 21, MIKE 3, MIKE SHE, etc. This article chose MIKE 21 model, with 2 other modules: HD and EcoLab, to simulate the possibility of pollutants dispersion in wastewater in the canal. Even though the MIKE model has been applied with consideration of the tidal regime by several previous researchers, most of its applications were carried out in large river basins with long time-series hydrological data. The application of the MIKE model is relatively diverse, being related to sea river dynamics, oil spills, turbidity, and some main pollution parameters in domestic wastewater.

Input data

Topographic data: Topographic data was referenced from global information https://earthexplorer.usgs.gov/; a topographical map at 1/2,000 scale, established in 2015, was collected from the Ministry of Natural Resources and Environment.

Hydrological and oceanography data: The study area (Figure 1) has 3 major river systems: Ong Doc (also known as Tac Thu river), Ganh Hao, and Bay Hap river. Two hydrological stations of Ganh Hao station and Ong Doc station (corresponding to the East and West boundary of the area towards the sea) are located in the study area. This article used the water level data at two stations to determine the calculated boundary conditions.

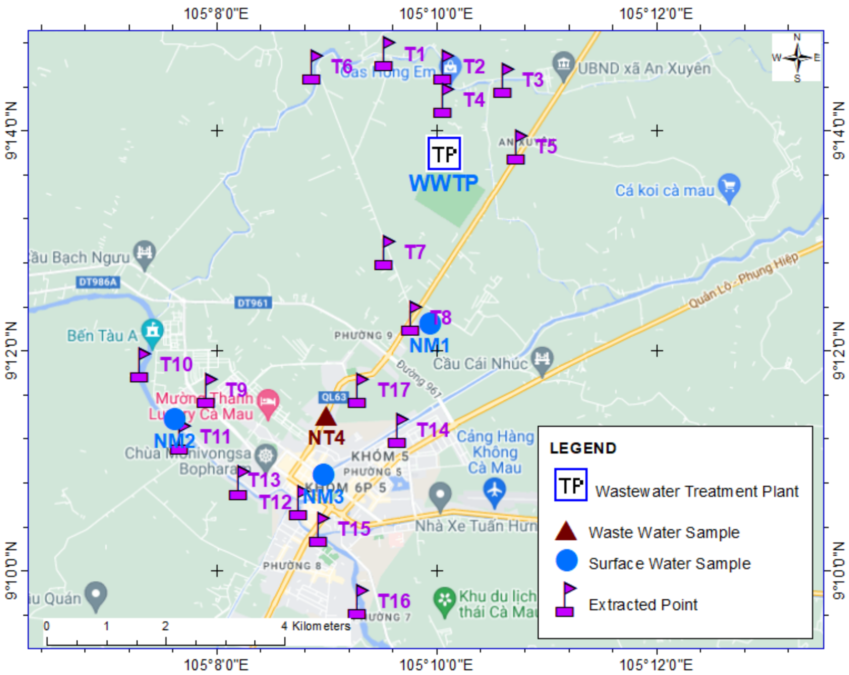

Figure 1. Study area

This article used tidal data, which was published in the article results of the southwestern coastal area [11]. The tide regime in this area is irregular. The tidal amplitude gradually increases from Ha Tien to Ca Mau, ranging from 0.7–1.3 m. The tidal characteristics of the river system in this area are dominated by the tidal regime of the East Vietnam Sea and Thailand bay.

Water quality data: From 2020 to 2021, the authors have conducted many field trips to the plant area and surrounding to investigate on natural conditions (flow, water level, tidal regime in Thong Nhat canal and Tac Thu river) and socio-economic conditions (population, current status of wastewater collection and treatment). Simultaneously, samples of surface water and wastewater were collected and analyzed at the laboratory of the Center for Environmental Technology, Institute of Physics, Vietnam Academy of Science and Technology, with a sampling frequency of 3 times in 2021, respectively, March 3–4, 2021; July 7–8, 2021; and May 11–12, 2021. The position of water sampling points is listed in Table 1 and Figure 1.

The analysis results show that Thong Nhat canal's surface water quality at the wastewater receiving point of the plant is relatively good; however, TSS concentration exceeds the standard at the time of the rainy season (July); NH_4^+concentration is approximately reaching the limit value. The value of 3 analyzes for the parameters are as follows: TSS concentration: 48–53 mg/L; BOD_5 value: 10.1–13.6 mg/L; NH_4^+ concentration: 0.32–0.89 mg/L; Coliform density 4,600–6,400 MPN/100 mL.

Table 1. The position of water sampling points

No.	Sample	Latitude	Longitude	Sampling point description
1	NM1	09°12'14,9"	105°09'56,5"	The point is in Thong Nhat canal, which is receiving point of the plant's wastewater
2	NM2	09°11'22,8"	105°07'37,4"	The point is in Thong Nhat canal which is about 300 m upstream from the receiving point of the plant's wastewater
3	NM3	09°10'42,5"	105°08'38,8"	The point is a junction of Tac Thu river and Thong Nhat canal
4	NT4	09°11'24,8"	105°09'00,5"	Wastewater sample at Nguyen Trai Street near Ca Mau Provincial Party Committee Politics School of Ward 9

To identify the effects of wastewater from the plant on the environment, we assessed the most unfavorable hydrological conditions, the dry season, for parameters of BOD_5, TSS, NH_4^+, and total Coliform in the period from 3–7 hours. Calculation results are extracted in two-dimensional and point distributions on both sides of the waste source, with priority given to densely populated areas with high sensitivity.

Seventeen points are extracted: T1 to T6 are used to assess the impact of the waste sources in the upstream area; points from T7 to T17 are used to evaluate the scope of dispersion and the impact of the waste sources in the downstream area (Figure 1). The extracted points are the basis for assessing the extent of pollutant transmission according to 2 selected scenarios.

Calculated Scenarios

In domestic wastewater, the main pollutant component is organic matter. Therefore, 4 parameters of TSS, BOD_5, NH_4^+, and total Coliforms were selected to evaluate water quality under 2 scenarios. The wastewater sample at Nguyen Trai Street is chosen as the basis value for the calculation and design of the wastewater treatment system after multiplying by a safety factor of 1.2–1.3 for each criterion (Table 2). In scenario 1, the WWTP is being operated inefficiently, and the wastewater has not been treated up to standards. Maximum calculation in case the processing performance = 0. In scenario 2, WWTP is being operated efficiently. The concentration of 4 components in wastewater is lower than the critical value of National regulation on domestic wastewater QCVN 14:2008/BTNMT (column *B*, *K* = 1).

The dry season was selected for simulation time because the pollution level was the highest. The tide level fluctuated in the range of 1.2–1.3 m at that time. According to the prevention and response plan of the plant's incident, the time to solve problems for the wastewater treatment system is about 3–7 hours (S1). Due to the system's characteristics, there are many machines and underground tanks, so the treatment processing usually takes about 6 hours. Therefore, 2 simulation times at 3 hours and 7 hours were selected for both scenarios to serve as a basis for comparison, control, and evaluation.

Table 2. Concentration of parameters in 2 scenarios

Scenario	Item	TSS (mg/L)	BOD_5 (mg/L)	NH_4^+ (mgN/L)	Coliforms (MPN/100 mL)	Capacity (m^3/day)
1	Untreated wastewater (Actual measured value of wastewater at Nguyen Trai Street has been multiplied by a safety factor of 1.2–1.3)	200	220	30	21,000	8,000
2	Treated wastewater (Colum B, QCVN 14:2008/BTNMT)	100	50	10	5,000	8,000

Model setup

Based on collected topographical and hydrographic data, we set up the calculation area, grid and boundary with the plant as the center, extending in four directions of an average of 6–10 km covering all major river systems, tributaries and related small canals in Ca Mau city (Figure 1). The calculation boundary is shown in Figure 2, and it consists of 5 boundaries in which boundary 1 is in the land. Boundary 1 is selected so that at the calculation conditions, it will not be flooded. The remaining boundaries are open boundaries, including boundary 2, boundary 3, boundary 4, and boundary 5.

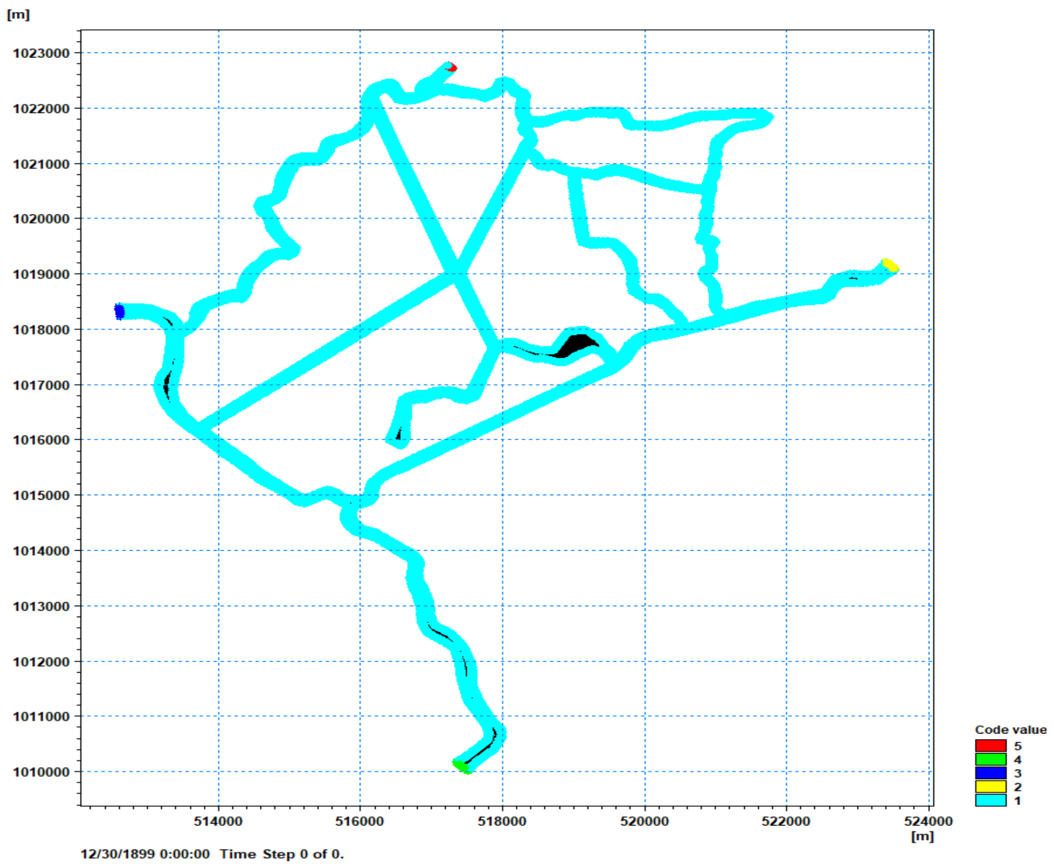

Figure 2. Chart of calculated boundary

The calculation of spread and distribution of water quality elements for Thong Nhat canal is based on hydrodynamic processes and analyzed results. The detailed calculation grid is subdivided with high resolution, the smallest grid size is 1.5 m and the largest is 4.5 m. Depending on the location and width of the channel, the grid setup will be adjusted to suit the actual terrain (Figure 2).

The set of input parameters for calculation includes hydraulic parameters and pollutant parameters. Three main parameters to calculate hydraulics are roughness coefficient with values from 36.0–48.0, turbulent viscosity coefficient at 0.26, and horizontal diffusion coefficient at 1.0. These parameters are determined based on actual data that were measured on 11/5/2021, along with observed data at Ganh Hao and Ong Doc stations.

Calibration and validation

The Nash-Sutcliffe model efficiency coefficient [12] is used in this article to assess the accuracy of hydrological models. It is defined as:

$$R^2 = \frac{\sum_{1}^{N}(H_i - \overline{H})^2 - \sum_{1}^{N}(H_i - H_{ci})^2}{\sum_{1}^{N}(H_i - \overline{H})^2}$$

where: H_i is the observed velocity (water level) at time i; $\overline{H}$ is the mean of observed velocity (water level); H_{ci} is the calculated velocity (water level) at time i; N is the total number of calculated data.

The hydraulic model is calibrated based on the actual measured data of water level, starting from 9 am on May 11, 2021. The calibration results are shown in Figure 3. Nash index resulted in $R^2 \geq 0.81$, which qualifies the hydraulic model for the next calculation steps. Compared with the calculated data, the actual measured data has a smaller oscillation cycle. According to past surveys, human activities have affected the water level fluctuations; however, the level of influence is partial, causing errors in the measurement results of water levels.

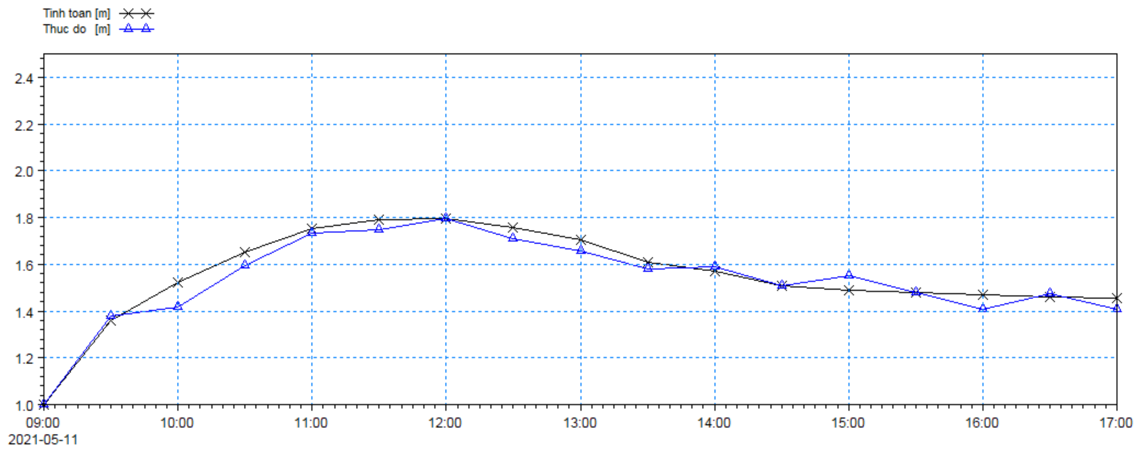

Figure 3. Result of calibration of water level in the period of additional measurement

RESULTS AND DISCUSSION

In general, the process of pollutant dispersion depends mainly on the tidal regime. The calculation results in the high tide phase show the trend of dispersion towards Ca Mau city. In contrast, in the low tide phase, the concentration of polluted components tends to move to the North.

Scenario 1

In the case of scenario 1 (the WWTP is being operated inefficient or not performed), waste source will significantly affect the receiving source of the Thong Nhat canal (Figures 4–7). The pollutant concentrations are high at *T*2, *T*4, *T*5 (upstream), *T*6, *T*7, and *T*8 (downstream). After 7 hours of calculation, the positions of *T*9 to *T*17 will not be affected by the pollutants.

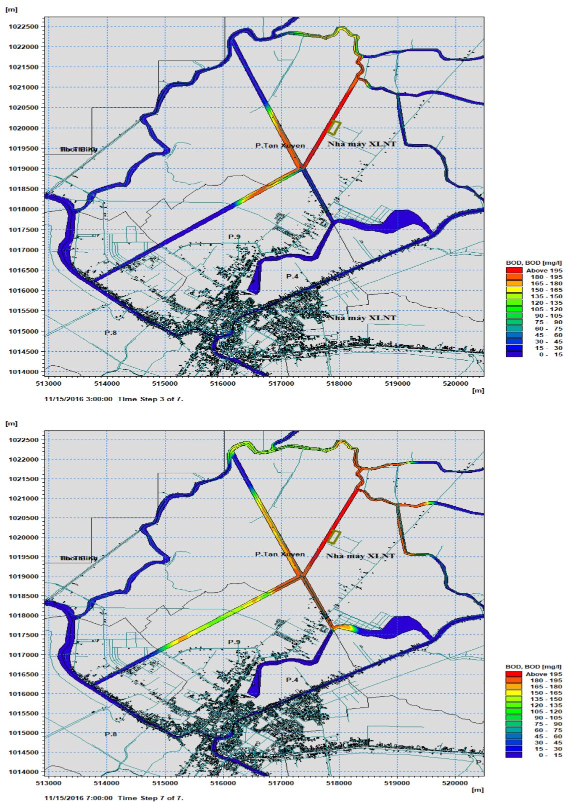

Figure 4. Distribution of BOD_5 values after 3 hours and 7 hours (Scenario 1)

The concentrations of polluted components tend to decrease gradually in the upstream and downstream of receiving wastewater.

TSS concentration in the Thong Nhat canal tends to increase and obtains the highest values at *T*4 and *T*7 positions. The highest concentration exceeds the critical value in national regulation on surface water quality (QCVN 08-MT:2015/BTNMT, column B1) by about 3,2 times.

The BOD_5 value reaches the highest value at position of *T*4 (about 0.8 km upstream) and *T*7 position (about 1 km downstream from the waste source). At other locations, pollutant concentrations decrease with distance.

The NH_4^+ concentration reaches the highest value at *T*4, and *T*7 positions exceed about 32 times compared to QCVN 08-MT:2015/BTNMT (column B1) and tends to decrease gradually at positions of *T*5, *T*6, *T*2, and *T*8. However, the pollution concentrations are still relatively high at these positions.

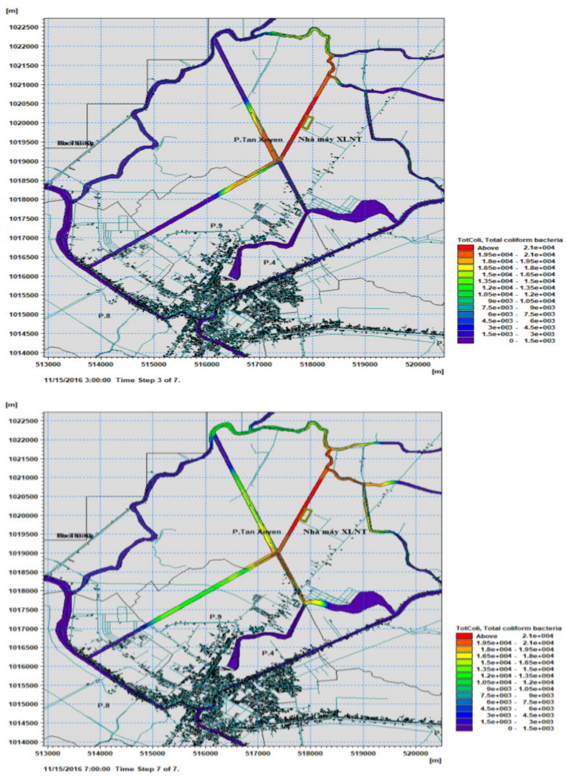

Figure 5. Distribution of total coliform index after 3 hours and 7 hours (Scenario 1)

The total Coliforms also vary similarly at different positions; the values exceed QCVN 08-MT:2015/BTNMT (column *B*1) at about 2.8 times at *T*4 and *T*7 positions and about 1.6–2.6 times at the *T*2, *T*5, *T*6, and *T*8 positions.

According to the calculated results, the concentration of pollutants discharged from the WWTP into the Thong Nhat canal raised the pollutant concentration in the channel, which exceeds the critical value. Although the concentration of pollutants in the wastewater decreases with the discharge of natural water flow as well as the self-purification of receiving sources, over time, the concentration of contaminants that are harmful to the environment will increase; the self-purification ability of the receiving source will reduce, significantly affecting the water quality of Thong Nhat canal and Tac Thu river and becoming detrimental to water users [13].

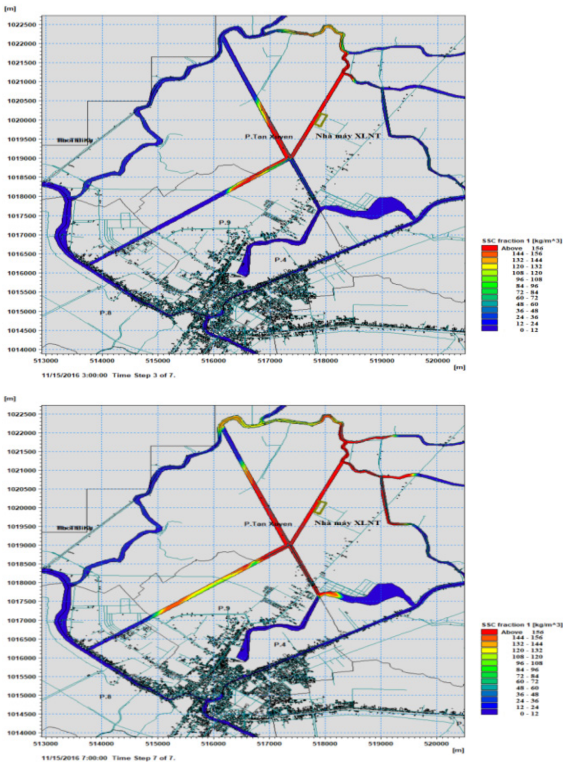

Figure 6. Distribution of TSS concentration after 3 hours and 7 hours (Scenario 1)

After about 1 hour, the high concentration of pollutants disperses to *T*4 and *T*7 positions. The pollutant concentration spreads to the *T*2 place after about 2 hours, to the *T*1 position after 3 hours, to the *T*5 position after about 4 hours, to *T*6 and *T*8 positions after 5–6 hours, and *T*3 position after about 7 hours.

According to the results of this scenario, the water quality of the Thong Nhat canal has significant fluctuation. If the plant's treatment capacity is zero, it takes 5 hours to affect the city; the first affected location is the segment flowing through Ward 9, a densely populated ward with the distribution characteristics following the canal system; therefore, polluted water will adversely affect these subjects.

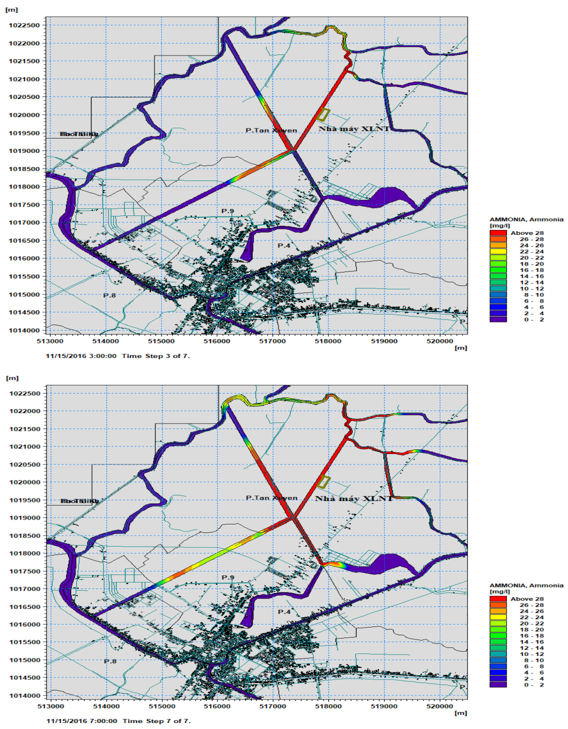

Figure 7. Distribution of NH_4^+ concentration after 3 hours and 7 hours (Scenario 1)

Scenario 2

In scenario 2 (Figures 8–11), the WWTP of the plant is being operated stably and efficiently; it is assumed that the concentration of treated pollutants satisfies QCVN 14:2008, columns *B*, *K* = 1 before being discharged into the receiving source. In this case, the pollutant concentrations at almost positions are within the critical values of QCVN 08-MT:2015/BTNMT (column *B*1), except for the TSS concentration that exceeds the standard by about 1.5 times at *T*4 and *T*7 positions; this is due to the current TSS concentration in the Thong Nhat canal is already high, 1.3–1.5 times higher than the standard as mentioned above.

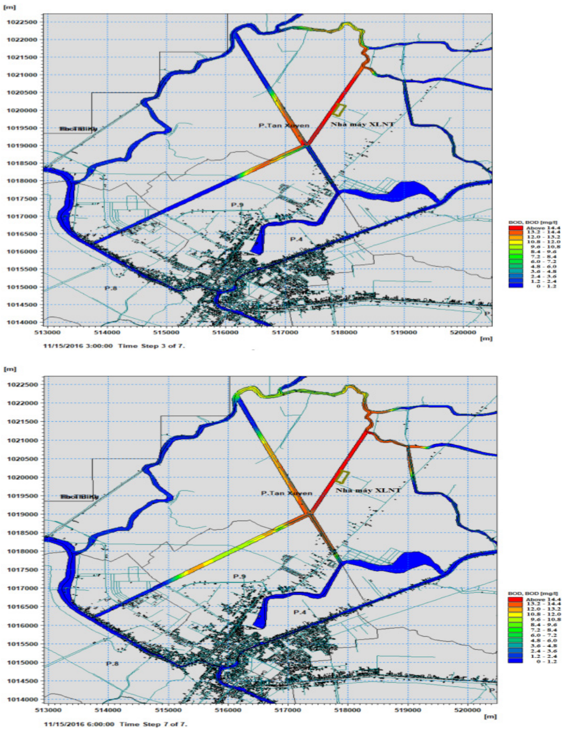

Figure 8. Distribution of BOD_5 values after 3 hours and 7 hours (Scenario 2)

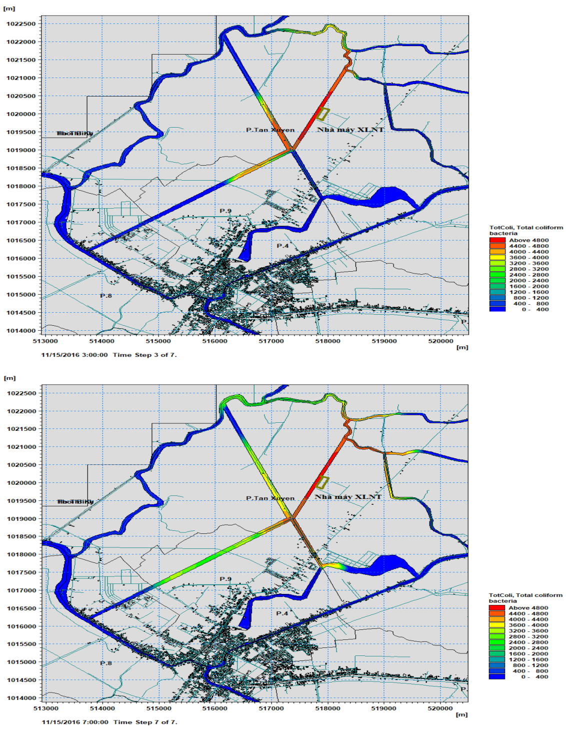

Figure 9. Distribution of total Coliforms index after 3 hours and 7 hours (Scenario 2)

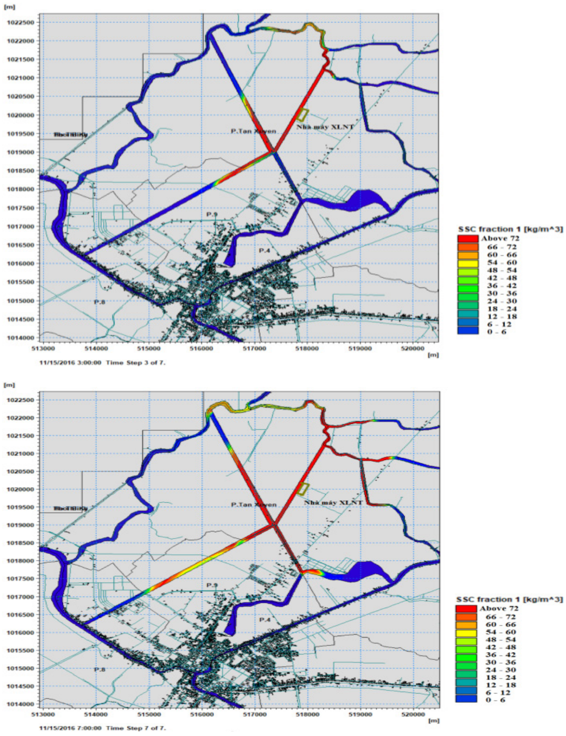

Figure 10. Distribution of TSS concentration after 3 hours and 7 hours (Scenario 2)

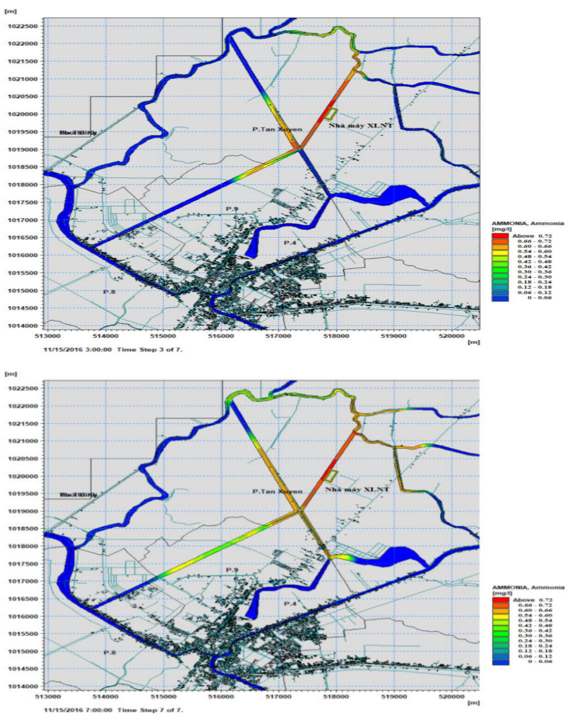

Figure 11. Distribution of NH_4^+ concentration after 3 hours and 7 hours (Scenario 2)

The pollutant parameters that affect the canal water quality exceed the critical value in column *B*1, QCVN 08-MT:2015/BTNMT in both scenarios. Thus, the concentrations of pollutants discharging into the Thong Nhat canal in scenario 1 are much higher than scenario 2. In both scenarios, water quality in the canal is altered within < 2 km from the discharge source. Water quality becomes more stable at a distance of over 2 km and is almost unaffected at a distance of 4 km (after 7 hours).

CONCLUSIONS

The calculation results show that in scenario 1 the WWTP is being operated inefficiently, and the wastewater has not been treated up to standards. The highest concentrations of pollutants were at *T*2, *T*4, *T*5, and *T*6 positions (within a distance of less than 1 km from WWTP to upstream), *T*7 and *T*8 positions (within a span of less than 1 km from WWTP to downstream) near the discharge source. The value of TSS, BOD_5, NH_4^+, and Coliforms tend to peak at *T*4 and *T*7 positions with a distance of 0.8–1 km downstream from the discharge point. The variation of concentration is also clearly shown over time; after about 1 hour, the pollutant is dispersed to *T*4 and *T*7 positions, corresponding to about 1 km, while after about 7 hours, the pollutant concentration is disseminated to the *T*3 position.

In scenario 2 (the WWTP of the plant is being operated stably and efficiently), the pollutant concentrations at all positions are within the critical value of QCVN 08-MT:2015/BTNMT (column *B*1) except for the TSS concentration. In both scenarios, water quality in the Thong Nhat canal varies within less than 2 km from the discharge source. Water quality gradually stabilizes from 2 km away and is almost unaffected at a distance of 4 km (after 7 hours).

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REFERENCES

[1] H Ismail, A., and A Abed, G., 2013. BOD and DO modeling for Tigris river at Baghdad city portion using QUAL2K model. *Journal of Kerbala University*, *9*(1), 257–273.

[2] Hadgu, L. T., Nyadawa, M. O., Mwangi, J. K., Kibetu, P. M., and Mehari, B. B., 2014. Application of Water Quality Model QUAL2K to Model the Dispersion of Pollutants in River Ndarugu, Kenya. *Computational Water, Energy, and Environmental Engineering*, *3*(04), 162–169. doi: 10.4236/cweee.2014.34017

[3] Chanudet, V., Smits, J., Van Beek, J., Boderie, P., Guérin, F., Serça, D., Deshmukh, C., and Descloux, S., 2016. Hydrodynamic and water quality 3D modelling of the Nam Theun 2 Reservoir (Lao PDR): predictions and results of scenarios related to reservoir management, hydrometeorology and nutrient input. *Hydroécologie Appliquée*, *19*, 87–118. https://doi.org/10.1051/hydro/2014009

[4] Liang, J., Yang, Q., Sun, T., Martin, J. D., Sun, H., and Li, L., 2015. MIKE 11 model-based water quality model as a tool for the evaluation of water quality management plans. *Journal of Water Supply: Research and Technology—AQUA*, *64*(6), 708–718. https://doi.org/10.2166/aqua.2015.048

[5] Panda, U. S., Mahanty, M. M., Rao, V. R., Patra, S., and Mishra, P., 2015. Hydrodynamics and water quality in Chilika lagoon-A modelling approach. *Procedia Engineering*, *116*, 639–646. https://doi.org/10.1016/j.proeng.2015.08.337

[6] Ikhwani, H., Zikra, M., Sukmasari, N. A., Angraeni, G., Tanaka, H., Umeda, M., and Kure, S., 2015. Modelling of the COD, TSS, phosphate and nitrate distribution due to the sidoardjo mud flow

into Porong River Estuary. *Procedia Earth and Planetary Science*, *14*, 144–151. https://doi.org/10.1016/j.proeps.2015.07.095

[7] Tuan, N. V. A., Hung, N. Q., Son, N. T., and Lien, N. T., 2016. Application of MIKE 11 model to simulate the spread of contaminants caused by aquaculture activities on some major rivers in Quang Tri province. *J. Sci. Hanoi Natl. Univ*, *32*, 250–255. (in Vietnamese).

[8] Oliveira, V. H., Sousa, M. C., Morgado, F., and Dias, J. M., 2019. Modeling the impact of extreme river discharge on the nutrient dynamics and dissolved oxygen in two adjacent estuaries (Portugal). *Journal of Marine Science and Engineering*, *7*(11), 412. https://doi.org/10.3390/jmse7110412

[9] Tuan, L. P., Doanh, L. S., Kim Oanh, V. T., Khuong, L. D., and Vuong, D. H., 2019. Application of a hydrodynamic model for river upstream water quality assessment in Vietnam. *Journal of Civil and Environmental Engineering*, *9*(2), 1–8.

[10] Ngo, T. M., and Phan, T. T. H., 2021. Simulation of wastewater dispersion of recycling scrap paper from Muc Son Paper factory to the downstream Chu river. *Vietnam Journal of Marine Science and Technology*, *21*(3), 361–374. doi: 10.15625/1859-3097/15975

[11] Hien, N. X., and Quyen, L. D., 2019. Unfavorable combination of Southeast monsoon and tide on sea dyke in the Southwestern region on August 3rd, 2019. *Vietnam Journal of Hydrometeorology*, *704*(08), 1–7. (in Vietnamese).

[12] Nash, J. E., and Sutcliffe, J. V., 1970. River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology*, *10*(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6

[13] Preisner, M., 2020. Surface water pollution by untreated municipal wastewater discharge due to a sewer failure. *Environmental Processes*, *7*(3), 767–780. https://doi.org/10.1007/s40710-020-00452-5