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Application of MIKE model for simulation of wastewater dispersion in the project of eco-tourism and residential areas of Rach Tram - Phu Quoc, Kien Giang, Vietnam

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ABSTRACT

This study aims to explore the transmission of pollutants from the domestic wastewater of the Rach Tram - Phu Quoc eco-urban project. To achieve this, the Ecolab module of the Mike model is employed. The dispersion of pollutants is influenced by both hydraulic and wind conditions. Notably, under southwest wind condition, the dispersion of pollutants is considerably more pronounced compared to that observed during the Northeast monsoon. Pollutant concentrations exhibited a tendency to move upstream along the Rach Tram river during high tide, while during low tide periods, they tended to move towards the sea. The results of the study indicated that concentrations of Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5), Ammonium (NH_4^+), and Total Phosphorus (TP) in the Rach Tram River and its estuary were found to be 3–8 times higher than the defined standard of Vietnam. However, when appropriate wastewater treatment measures were implemented (scenario 2), the levels of pollutants were observed to be lower the permissible environmental protection standards.

Keywords: Mike model, wastewater, Rach Tram - Phu Quoc, Vietnam.

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INTRODUCTION

Phu Quoc is the largest island and is well-known as a famous tourist destination in Vietnam. To promote tourism development, many buildings and resorts have been constructed on the island recently. The ecotourism areas in Rach Tram planned to be built in Bai Thom area, Phu Quoc Island, with an area of 173.53 hectares, hosting 7,000 residents and visitors (the project of ecotourism and residents' Rach Tram areas).

The increasing population density has pressured the island's environment, especially the domestic wastewater treatment from urban areas. After wastewater is discharged into the river and ocean areas, the hydraulic and wind regimes diffuse and disperse pollutants. Therefore, the dynamics process is essential in distributing, transmitting, and diluting wastewater from the discharged source. Many researchers had applied models to assess pollution levels, such as WASP (Water Quality analysis simulation program), QUAL2K (River and Stream water quality model), DELFT 3D, and MIKE.

Many studies use various models of pollution dispersion in the river and ocean. For example, Huynh Vuong Thu Minh et al., [1] used Mike 11 to quantify the spatio-temporal dynamics of water quality parameters, such as Biochemical Oxygen Demand (BOD_5), Dissolved Oxygen (DO) and temperature, in the Long Xuyen Quadrangle area of the Vietnamese Mekong Delta. Nguyen Chi Cong et al., [2] used the biological process to study the self-cleaning process in Nha Trang bay's environment receiving the domestic wastewater from the Cai river. Cao Thi Thu Trang et al., [3] also applied the Deflt 3D model to assess the concentration of high pollutant concentrations in the Tam Giang - Cau Hai lagoon area, Thua Thien-Hue Province. The 3-D ECOHAM numerical model was used to investigate nutritional dynamics in Van Phong bay (Nha Trang - Khanh Hoa) and predict the seasonal variations of nitrogen and phosphorus concentrations in the bay [4]. Nguyen Thi Huyen applied the Mike 21 model with the Ecolab module to evaluate the accessibility of receiving wastewater from the Vu Gia - Han estuary based on the change and distribution of BOD_5 concentration. Moreover, the Mike 21 FM ECO Lab module was applied to simulate the water quality and to identify the spreading of NH_4^+, which is used as a pollutant tracer in Da Nang bay [5–9].

Mike 21 & Mike 3 flow model FM ECO Lab module is a state-of-the-art numerical tool for 2D and 3D ecological modeling of ecosystems. The combination of a user-friendly interface, open access to the governing equations, and the coupling of Mike ECO lab to the Mike 21 & Mike 3 is a powerful tool typically applied in environmental water quality studies in coastal areas, estuaries, and lakes [3, 9–11].

Therefore, this study aims to investigate pollutant transmission from of the Rach Tram eco-urban project's domestic wastewater using the ECO Lab module of the Mike model, thereby contributing to environmental management in Phu Quoc Island [12–15].

METHODS

Study area

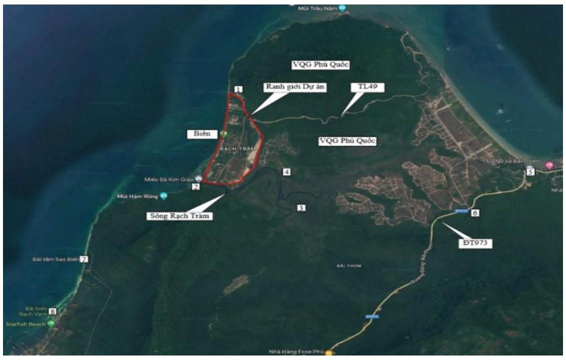


Figure 1. The study areas

The project of Ecotourism and Residents Rach Tram areas had been accessed according to Decision No 2257/QD-UBND September 22, 2021, of the People's Committee of Kien Giang province about planning and building and residents Rach Tram in Bai Thom Village, Phu Quoc City with the 173.53 ha. This study is located north of Phu Quoc Island, with the boundary including the East and South near Phu Quoc National Park. The West of the project borders the sea in the South of the project, close to the Rach Tram River (Fig. 1).

Model application

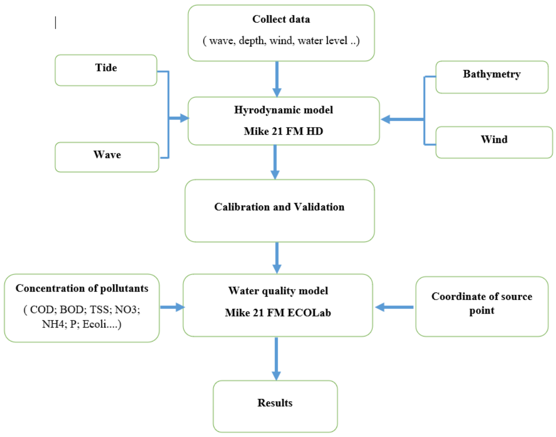


Figure 2. Study approach flowchart

The study combined hydraulic modules Mike 21 FM and Ecolab, simulating the process of pollutant transmission from domestic wastewater of Rach Tram eco-urban area project, Phu Quoc Island. The study approach flowchart was shown in Figure 2.

The model is based on the solution of the three - dimensional incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and hydrostatic pressure. The local continuity equation is written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=S \qquad (1)$$

And the two horizontal momentum equations for the *x*- and *y*- component, respectively.

$$\begin{aligned}&\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\\&-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{g}{\rho_0}\int_z^{\eta}\frac{\partial \rho}{\partial x}dz-\\&-\frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+\\&+F_u\frac{\partial}{\partial z}\left(v_t\frac{\partial u}{\partial z}\right)+u_s\end{aligned} \qquad (2)$$

$$\begin{aligned}&\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}-\\&\frac{g}{\rho_0}\int_z^{\eta}\frac{\partial \rho}{\partial x}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+F_u\frac{\partial}{\partial z}\left(v_t\frac{\partial u}{\partial z}\right)+u_s\end{aligned} \qquad (3)$$

$$\begin{aligned}&\frac{\partial v}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}=-fu-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial y}-\\&\frac{g}{\rho_0}\int_z^{\eta}\frac{\partial \rho}{\partial y}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+F_v\frac{\partial}{\partial z}\left(v_t\frac{\partial v}{\partial z}\right)+v_s s\end{aligned} \qquad (4)$$

where: t is the time; x, y and z are the Cartesian co- ordinates; η is the surface elevation; d is the still water depth; $h = \eta + d$ is the total water depth; u, v and w are the velocity components in the x, y, and z direction; f is the Coriolis parameter; g is the gravitational acceleration; ρ is the density of water; S_{xx}, S_{xy}, S_{yx} and S_{yy} are components of the radiation stress tensor; v_t is the vertical turbulent (or eddy) viscosity; p_a is the atmospheric pressure of the discharge due to point sources and (v_s, u_s) is the velocity by which the water is discharged into the ambient water.

The biological and chemical transformation processes affecting state variable in an ecosystem (also called the ECO Lab equation) is specified for each ECO Lab state variable expressed by an ordinary differential equation, P_c given by DHI, 2004 as follows:

$$P_c = \frac{dc}{dt} = \sum_{i=1}^{n} process_i$$

in which: P_c = ECO Lab processes, c = the concentration of the ECO Lab state variable; n = number of processes involved for a specific state variable and process = user specified expression containing argument such as mathematical function, built in function, number, forcing, constants and state variable. The dynamics of advective ECO Lab state variable can be expressed by a set transport equations, which in nonconservative form can be written as:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = D_x\frac{\partial^2 c}{\partial x^2} + D_y\frac{\partial^2 c}{\partial y^2} + D_z\frac{\partial^2 c}{\partial z^2} + S_c + P_c$$

Let denote: u, v, w = flow velocity components; D_x, D_y, D_z = dispersion coefficients and S_c = sources and sinks. The transport equation can be rewriten as $\frac{\partial c}{dt} = AD_c + P_c$.

The term AD_c represents the rate of change in concentration due to advection (transport based on hydrodynamics) and dispersion, including source and sinks. AD_c is dependent on discretization and solved with a finite volume technique in Mike 21/3 ECO Lab.

The coupled set of ordinary differential equations defined in MIKE ECO Lab is solved by integrating the rate of change due to both the MKE ECO Lan processes and the advection-dispersion processes:

$$c(t+\Delta t) = \int_{t}^{t+\Delta t} (P_c(t) + AD_c)dt$$

The advection-dispersion contribution is approximated by $AD_c = \frac{c^*(t+\Delta t) - c^n(t)}{\Delta t}$.

The intermediate concentration c^* is found by transporting the MIKE ECO Lab state variable as a conservative substance using the AD module over a time period Δt. The ECO Lab numerical equation solver makes an explicit time integration of the above transport equations when calculating the cocentrations to the next step performed with different numerical solutions such as Euler, RK4, and RKQC.

Data sources

Bathymetry data

Bathymetry data of the study area used from the project document "Research, establish scientific arguments and propose orientations for marine spatial planning of Phu Quoc - Con Dao for sustainable development" Code No KC.09.16/11–15. The ratio of bathymetry in the study area was 1/10.000.

Wind data

The study used a series of long-term wind monitoring data at Phu Quoc marine station (10^{o}13'; 103^{o}58').

Wave data

The maximum wave height in the year reached 2.5–3 m with two main directions, SW accounting for 39% and WNW-N directions accounting for 19%; the remaining 42% of the total cases were still waves.

Water level data

The actual water level data measured at Phu Quoc station (10^{o}13'; 103^{o}58') was used to calculate and verify the hydraulic model. Global tidal level data provides for establishing hydraulic models in the study area.

Environment data

Water quality data from the the project's initial study was used for running models (Table 1).

Table 1. Water quality in the study area. Study site PQ1 (X = 1151008, Y = 441974): in Rach Tram river - receive wastewater during the project operation phase, PQ2 (X = 1151645, Y = 441589): in the coastal waters at the fishing village in the West of the project, PQ3 (X = 1153018, Y = 441968): in the coastal waters in the northwest of the project

No.	Name	Unit	Result			QCVN 10-MT:2015/BTNMT		
			PQ1	PQ2	PQ3	Aquaculture area, aquatic conservation	Beach area, water sports	Other areas
1	pH	-	6.7	7.8	7.9	6.5–8.5	6.5–8.5	6.5–8.5
2	DO	mg/L	5.4	6.7	6.9	≥ 5	≥ 4	-
3	BOD_5	mg/L	4.5	4.0	4.3			
4	NH_4^+	mg/L	0.54	0.06	0.08	0.1	0.5	0.5
5	TSS	mg/L	35	32	35	50	50	-
6	PO_4^{3-}	mg/L	0.03	0.03	0.05	0.2	0.3	0.5
13	Coliform	MPN/100 mL	3,900	1,500	1,200	1,000	1,000	1,000

[*Sourse:* Institute of environment technology and analysis (IETA), 2021]

RESULT AND DISCUSTION

Set up model

The study area was built with unstructured grids covering the entire area around Phu Quoc Island with different mesh densities. The mesh density in the coastal area was thicker than in the offshore area. 10,862 grid cells and 6,434 grid nodes were built (Figure 3). The large grid areas were used for model calibration and verification, and a small set of grids concentrated in the project area was used to simulate the project's wastewater dispersion process.

Bathymetry data

Bathymetry data of the study area used from the project document "Research, establish scientific arguments and propose orientations for marine spatial planning of Phu Quoc - Con Dao for sustainable development" Code No KC.09.16/11–15. The bathymetry ratio in the study area was 1/10,000 (Figure 3).

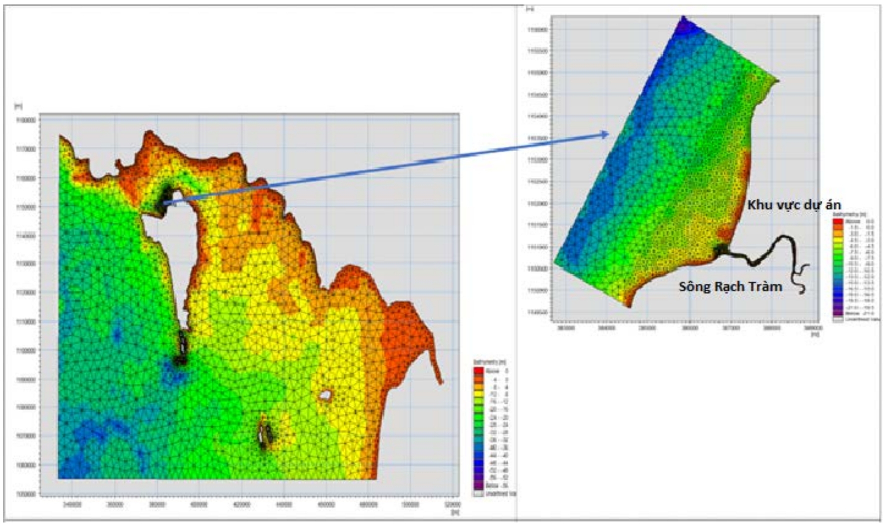


Figure 3. Computation grid in the study area

The setting of the simulation conditions

This study focused on calculating some quality indicators of basic water in time and space such as NH_4, TSS, BOD, and total Coliform, corresponding to the hydraulic boundary conditions and the waste sources. The parameter correction of the model Ecolab water quality was done mainly by changing the diffusion coefficient and Ecolab ecological indicators of pollutants.

Table 2. Hydraulic and water quality simulation conditions

Items		Contents
Model composition	Grid composition	Unstructured triangular grid system
	Number of grids	Number of grids for practical calculation: 10.862
	Wave input data	According to meteorological data measured for many years in Phu Quoc station (10°13’; 103°58’)
	Wind input data	Series of long-term wind monitoring data at Phu Quoc marine station (10°13’; 103°58’)
	Water level	Collected form water level of global tidal (2021)
Simulation conditions	Main water quality constants	Decay rate BOD (20°C) = 1/day
		Phosphorus process: Phosphorus content in dissolved BOD = 0.06, Half-Sat. Conc. for P-uptake = 0.005 mg/L
		Nitrification: 1st order decay rate = 0.05/*d*, Oxygen demand by nitrification, NH_4 to NO_2 = 3.42, Half-Sat. oxygen Conc. = 2 mg/L

Calibration and validation

Water level data measured at Phu Quoc station was used to calibrate the hydraulic model and the Nash coefficient was 0.863 (Fig. 4).

Data from the process of hydraulic calibration and simulation in 8/2021 was used to evaluate the stability of the model. The comparison results between the measured and calculated water levels were relatively homogeneous regarding the oscillation phase (the black line was calculated water level data, and the blue line was the measured value and achieved a Nash coefficient of 0.82).

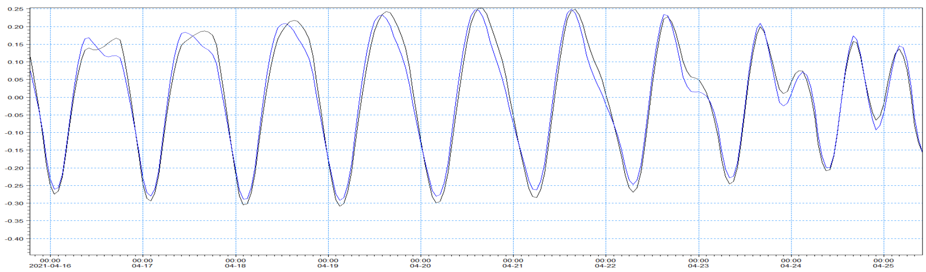


Figure 4. Comparison between measured and calculated water level

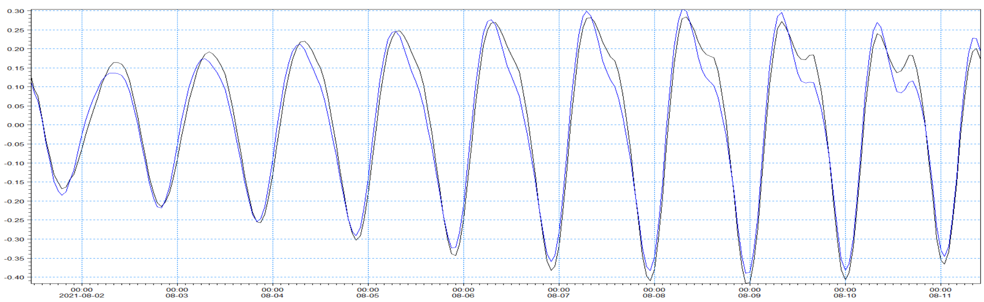


Figure 5. Comparison between measured and calculated water level in validation

Water quality model

The water quality propagation model was calculated with parameters BOD_5, NH_4, and PO_4^{3-}. The domain, grid, computation time, initial conditions, and boundary conditions were similar to the hydrodynamic model. In addition, the input parameters of the water quality model were taken from the analysis results and the reference values according to the model's instructions. Calibrate the model by comparing simulation results with continuous monitoring results in the field.

Table 3. Comparision between computer and observation value

Parameter	PQ1		PQ2		PQ3	
	Computer	Observation	Computer	Observation	Computer	Observation
BOD_5	4.65	4.5	4.13	4.0	4.42	4.3
NH_4^+	0.68	0.54	0.84	0.06	0.11	0.08
PO_4^{3-}	0.05	0.03	0.06	0.03	0.09	0.05

Building scenario simulation

When the water treatment factory comes into operation with a treatment capacity of 7,260 m^3/day, equivalent to 0.084 m^3/s, and discharged into the Rach Tram, it could impact water quality in the study area. Thus, two scenarios were considered in this study, as follows:

Scenario 1: The wastewater treatment plant is is needed to be more efficient, and be treated up to standards. Maximum calculation in case of treatment efficiency = 0, corresponding to the concentration of pollutants of pre-treatment wastewater.

Scenario 2: Wastewater treatment system works effectively. Wastewater is treated to meet QCVN 14:2008/BTNMT (column A, K = 1.0) equal to the allowable limit of the regulation.

The wastewater characteristic is domestic wastewater, with the main pollutant components being organic matter TSS, BOD_5, NH_4^+, PO_4^{3-}, and Total Coliforms. The concentration of these parameters in untreated wastewater exceeds the allowable limit of QCVN 14:2008/BTNMT many times (column A, K = 1.0). Thus, six parameters (TSS, BOD_5, NH_4+, PO_4^{3-}, and Total Coliforms) were selected to perform a pollutant spread assessment of wastewater discharge into Rach Tram river. Concentrations of pollutants in wastewater under each scenario were presented in Table 4.

Table 4. Concentrations of pollutants in wastewater

Senarios	TSS (mg/L)	BOD_5 (mg/L)	NH_4^+ (mg/L)	PO_4^{3-} (mg/L)	Total Coliforms (mg/L)	Discharge (m^3/day)
Scenario 1	250	250	50	15	21,000	7,260
Scenario 2	50	30	5	6	3,000	7,260

Simulate scenario 1

Simulate in the Northeast monsoon condition

Simulation results of the TSS concentration and distribution in the study area showed that during the first 7 hours after wastewater discharge, the TSS concentration was distributed in the area in the Rach Tram river, about 200 m away from the discharge site (220–240 kg/m^3). TSS concentration gradually decreased outside the river mouth, reached about 20 kg/m^3. After 12 hours of wastewater discharge, the turbidity dispersed to the sea and tended to shift to the west direction of the estuary. TSS distribution along the shoreline with concentrations of 20–140 kg/m^3 due to the effect of the flow regime during the Northeast monsoon.

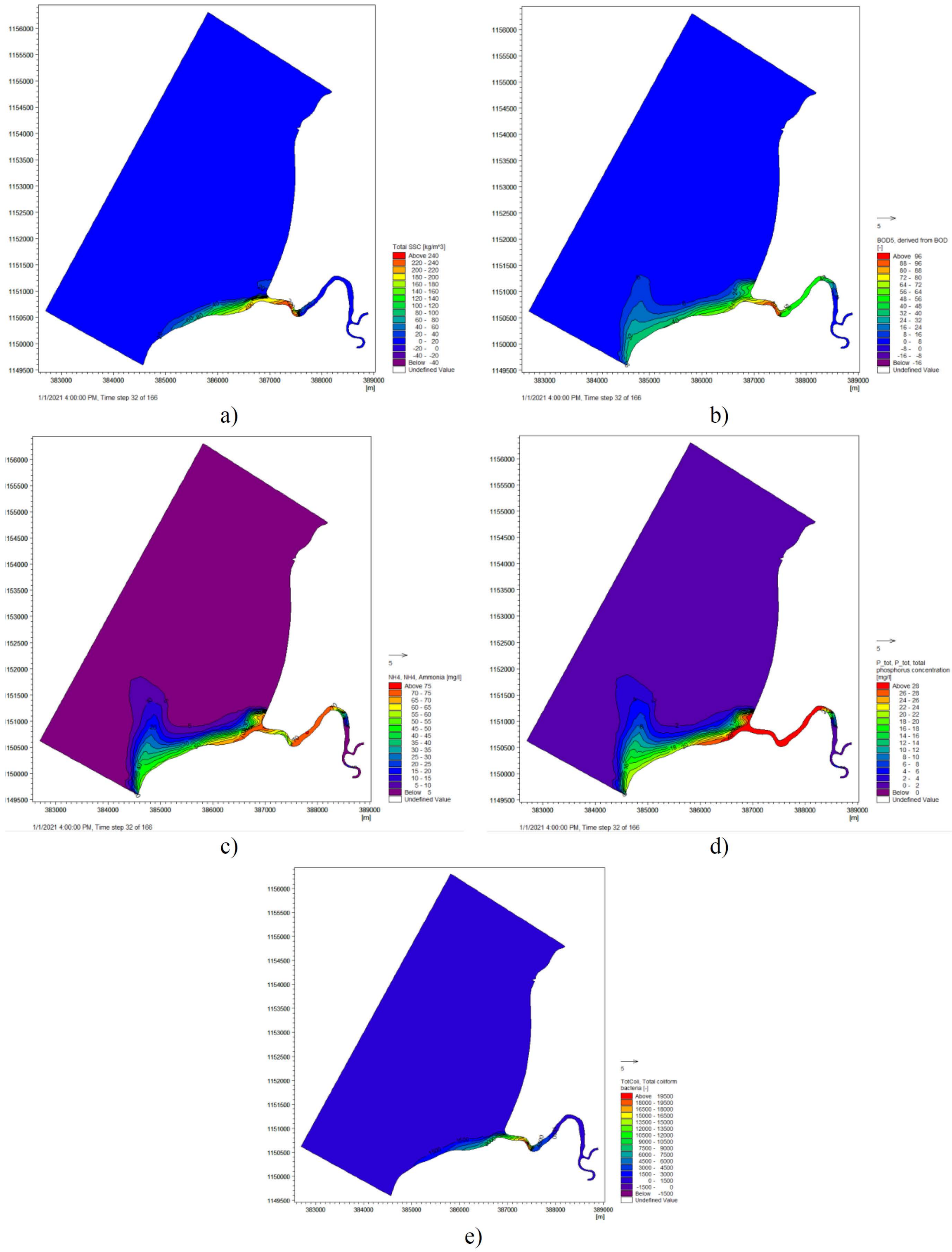


Figure 6. Concentration distribution of pollutants:
a) Concentration and distribution of TSS;
b) BOD_5; c) NH_4; d) Phosphorus; e) Coliform

Simulate in the Southwest monsoon condition

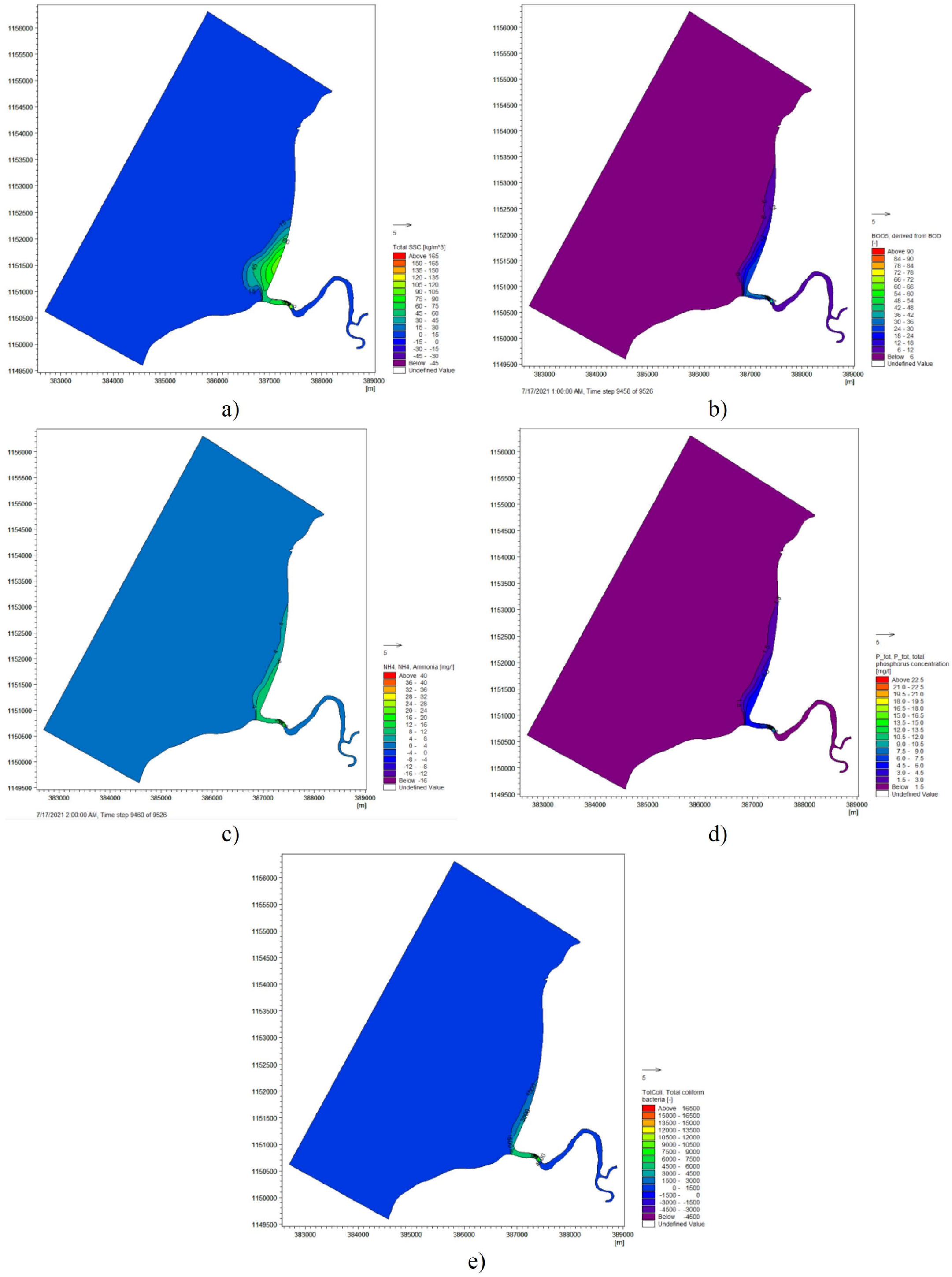


Figure 7. Concentration distribution of pollutants in the Southwest: a) Concentration distribution TSS; b) Concentration distribution BOD_5; c) Concentration distribution NH_4; d) Concentration distribution phosphorus; e) Concentration distribution coliform

This study chose some testing locations distributed along coastlines and river areas to extract concentrations of pollutants in the monsoon periods. The testing location is shown in Figure 8.

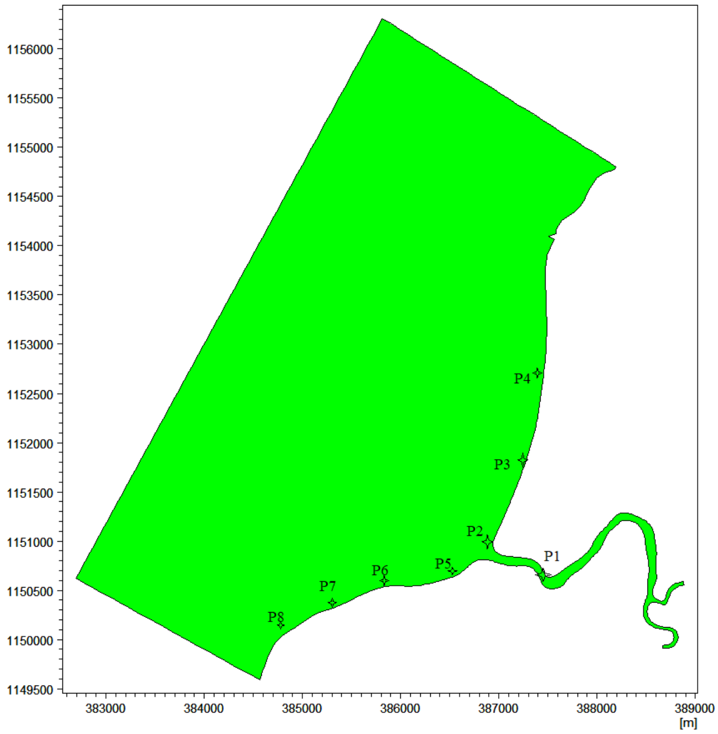


Figure 8. Testing location

BOD_5 concentration at P_1 (0.8 km from the discharge point to the estuary) was the highest (56.25 mg/L) in the southwest monsoon periods, higher than 8.8 according to the Norm of QCVN. In the coastal areas, the pollutant concentration tended to decrease gradually. The concentration of NH_4^+ at P_1 and P_2 reached the maximum value and exceeded the norm about 8.4 times in the northeast monsoon condition, at the P_5, P_6, P_7, and P_8 having NH_4^+ concentrations 17.46, 16.84, 15.26, and 12.67 mg/L, respectively.

Table 5. Comparison concentration BOD_5 and NH_4^+ at the study area

Point	NH_4^+ (mg/L)				BOD_5 (mg/L)			
	NE		SE		NE		SE	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
P1	23.29	18.93	25.49	21.07	49.16	39.49	56.25	49.97
P2	20.06	17.99	21.29	19.75	33.47	29.05	34.71	30.58
P3	14.70	3.34	14.61	13.36	10.32	8.21	25.16	26.12
P4	13.80	2.16	13.17	12.62	9.00	6.06	14.24	12.44
P5	17.46	15.23	5.02	4.02	30.01	32.23	7.23	6.32
P6	16.84	13.70	4.36	3.21	22.53	21.22	6.25	5.12
P7	15.26	11.53	3.21	2.01	17.51	13.06	4.54	2.41
P8	12.67	8.91	2.49	1.06	14.75	10.79	3.12	1.67

TSS concentration on the Rach Tram River reached the highest value at P_1 and P_2, exceeding about 3.4 times and 4.9 times higher than the standard value in the QCVN 08-MT:2015/BTNMT (column A1) in Northeast monsoon and Southwest monsoon conditions, respectively. TSS concentration decreased when the dispersion was in the offshore area.

The total coliforms exceeded the standard value by 2.7 times at P_1, P_2, and about 1.6–2.6 times at P_6, P_7, and P_8 in the northeast monsoon condition. In the southwest monsoon, the total coliforms at P_1 and P_2 exceeded the threshold about 2.2 times and gradually decreased at P_3, P_4, and P_5.

Table 6. Comparison of the Coliforms and TSS concentrations at the study area

Point	Coliform (mg/L)				TSS (mg/L)			
	NE		SE		NE		SE	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
P1	18156	13257	19396	16218	245.82	67.35	234.66	71.58
P2	12058	3806	5645	3900	142.23	30.21	138.56	35.58
P3	3726	315	5957	4904	13.86	8.65	98.25	20.38
P4	3726	298	5048	3563	11.65	5.63	62.27	10.77
P5	12321	4993	500	453	170.30	74.97	17.42	12.84
P6	6238	2439	352	235	79.66	30.31	13.06	11.42
P7	3726	1165	231	162	55.98	18.88	9.90	6.96
P8	3726	999	165	106	45.82	7.35	8.12	5.70

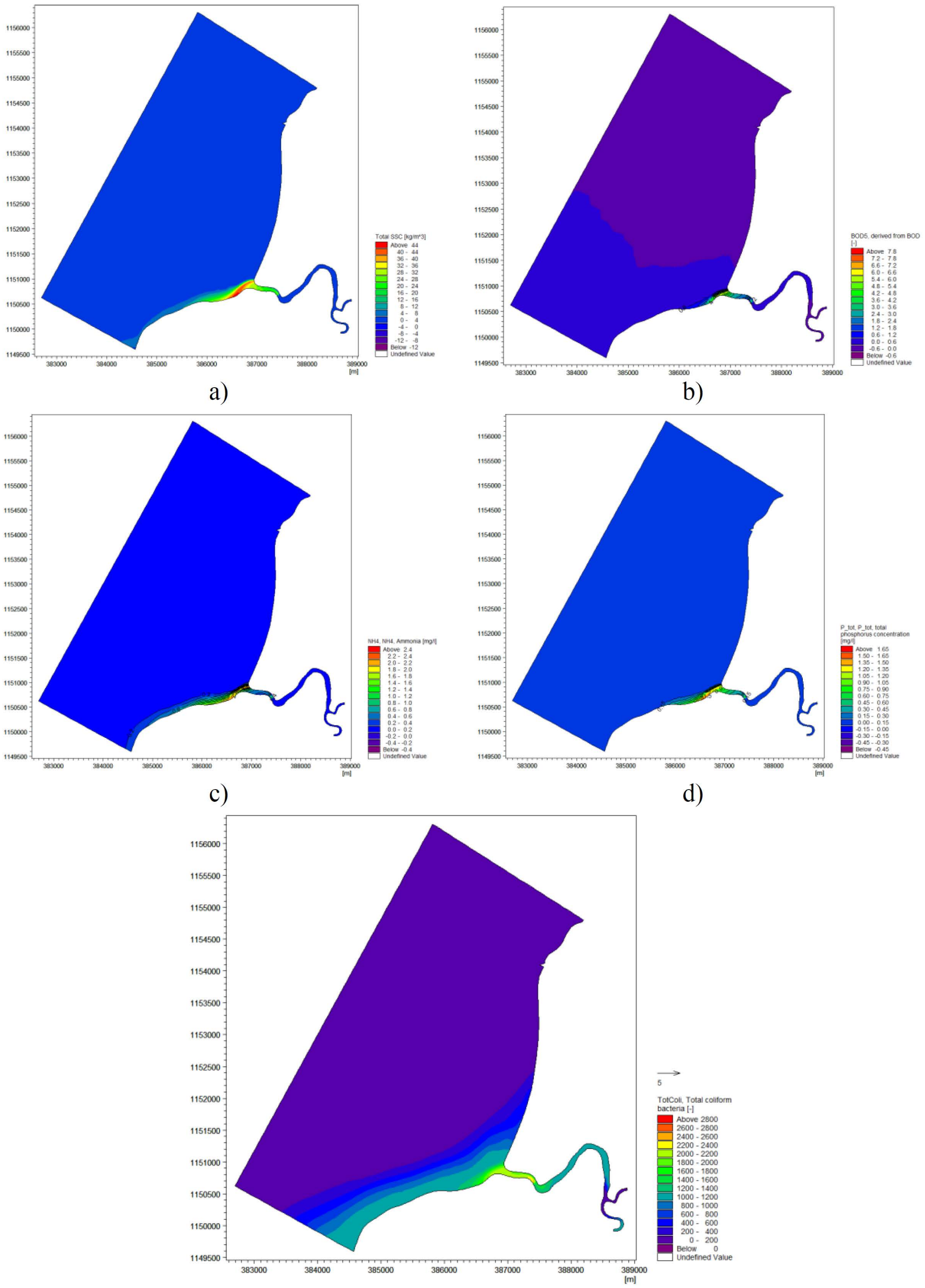
Table 7. Comparison of P concentration at the study area

Point	TP (mg/L)			
	NE		SE	
	Max	Mean	Max	Mean
P1	15.63	12.16	14.06	12.32
P2	13.39	10.67	12.53	11.03
P3	3.21	1.65	8.83	6.54
P4	2.32	1.13	6.50	5.77
P5	10.22	9.30	6.70	3.41
P6	9.39	8.85	5.06	3.06
P7	8.25	5.18	3.56	2.85
P8	7.01	3.25	2.78	2.05

The maximum total phosphorus (TP) concentration at P_1 and P_2 exceeded the norm about 3.7 times in the northeast and over 4.0 times in the southwest. The process of pollutant dispersion depends mainly on the tidal flow regime. In the ebb tide phase, the concentration of pollutants tends to shift outward to the sea. In contrast, the current had direction into the river in the high tide, which caused the pollutant concentration to move upstream of the river. Results in monsoon conditions showed that pollutant concentrations spread to the north during the northeast monsoon period and vice versa during the Southwest monsoon period.

Simulate scenario 2

Simulate in the Northeast monsoon condition



e)

Figure 9. Concentration distribution of pollutants in Northeast monsoon: (a) Concentration distribution TSS; b) Concentration distribution BOD5; c) Concentration distribution NH4; d) Concentration distribution P; e) Concentration distribution Coliform

Simulate in the Southwest monsoon condition

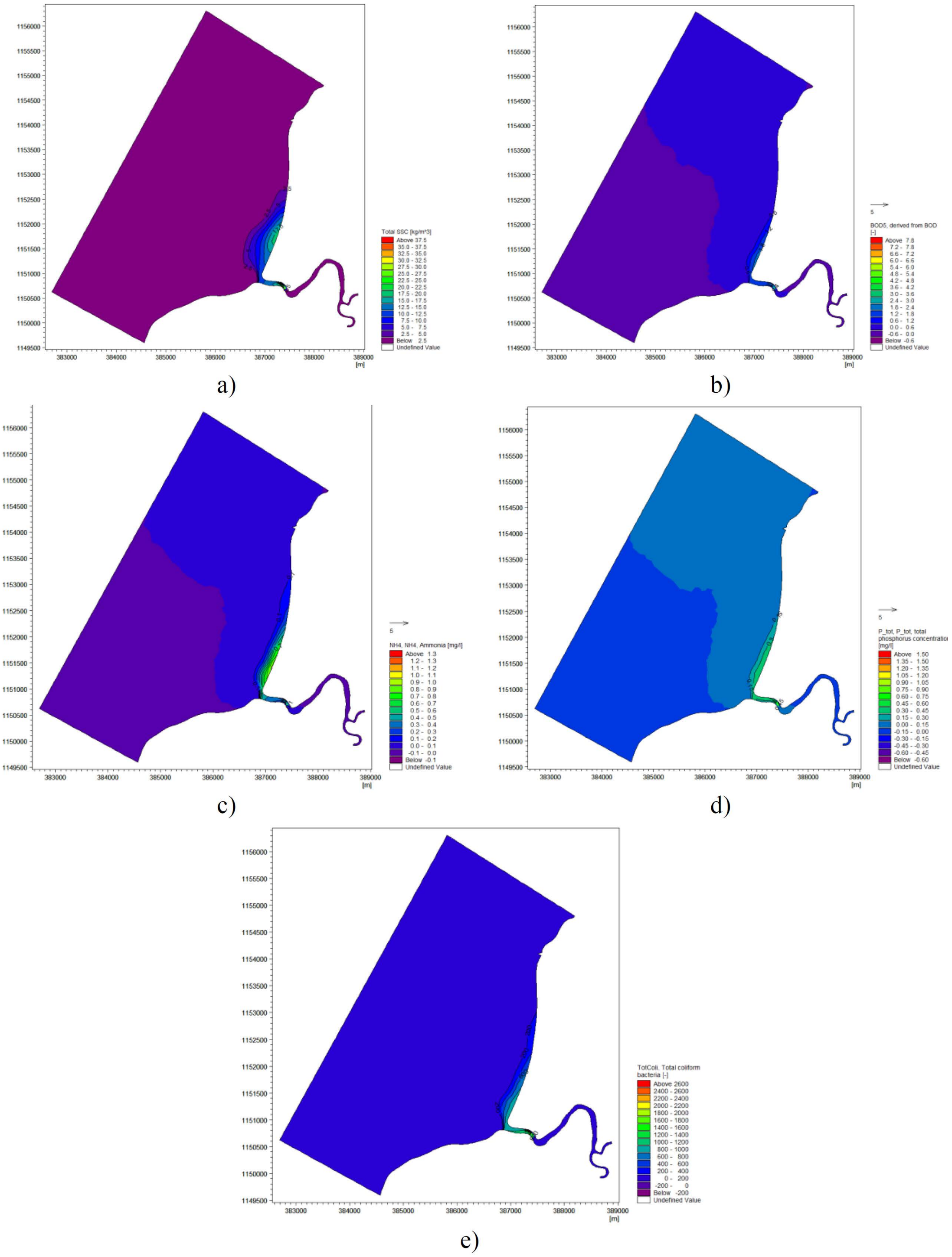


Figure 10. Concentration distribution of pollutants in southwest monsoon: a) Concentration distribution TSS; b) Concentration distribution BOD5; c) Concentration distribution NH4; d) Concentration distribution P; e) Concentration distribution Coliform

Table 8. Comparison concentration BOD_5 and NH_4^+ in the senario 2

Point	NH_4^+ (mg/L)				BOD_5 (mg/L)			
	NE		SE		NE		SE	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
P1	3.83	0.81	3.91	0.92	3.5	1.13	3.9	2.01
P2	3.55	0.68	3.63	0.83	2.4	0.97	2.63	1.12
P3	0.34	0.16	0.97	0.64	0.06	0.03	1.91	0.24
P4	0.24	0.06	0.76	0.57	0.03	0.02	0.61	0.12
P5	1.54	0.65	0.25	0.14	1.92	0.63	0.21	0.86
P6	0.63	0.55	0.12	0.10	1.8	0.51	0.19	0.63
P7	0.61	0.24	0.08	0.06	0.6	0.15	0.10	0.26
P8	0.54	0.19	0.05	0.03	0.4	0.09	0.07	0.12

Table 9. Comparison concentration Coliforms and TSS in the scenario 2

Point	Coliform (mg/L)				TSS (mg/L)			
	NE		SE		NE		SE	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean
P1	2363	1435	2456	1823	30.72	20.42	33.14	21.36
P2	1882	1036	1563	952	28.45	16.47	30.84	18.23
P3	345	156	1002	533	5.31	3.23	19.85	14.31
P4	206	103	553	384	3.26	2.35	13.18	12.80
P5	1735	956	320	102	26.88	14.04	6.59	5.62
P6	1352	693	100	35	23.49	8.85	3.87	3.0
P7	1245	418	56	26	16.17	5.81	3.24	1.6
P8	1127	372	32	15	12.42	4.07	2.75	1.3

Table 10. Comparion concentration P in the scenario 2

Point	P (mg/L)			
	NE		SE	
	Max	Mean	Max	Mean
P1	0.03	0.01	0.28	0.17
P2	0.76	0.34	0.16	0.05
P3	0.63	0.28	0.13	0.03
P4	0.19	0.06	0.08	0.02
P5	0.12	0.04	0.05	0.01
P6	0.03	0.01	0.28	0.17
P7	0.76	0.34	0.16	0.05
P8	0.63	0.28	0.13	0.03

Simulation results according to scenario 02 showed that the concentration of BOD_5, TSS, P, and NH_4 were lower than QCVN 14:2008 due to wastewater sources having been treated before being discharged into the Rach Tram river.

In general, during the Southwest monsoon period, the dispersion of pollutants was significantly larger than during the Northeast monsoon. The wastewater discharge location is near the Rach Tram Estuary, so the dispersion of pollutant concentration depends on the monsoon regime and tidal flow.

CONCLUSION

The dispersion of pollutant within the Rach Tram - Phu Quoc eco-urban project is primarily governed by the prevailing wind patterns and tidal currents. During periods of low tide, pollutants exhibit a tendency to migrate towards the open sea. Conversely, when high tide occurs, the propagation direction shifts further upstream into the river.

In the event of an ineffective or non-operational wastewater treatment system (scenario 1), the environment within the Rach Tram river vicinity and its estuary bears the brunt of wastewater impact. The most concentrated levels of are detected at two specific points: P_1 (adjacent to the discharge gate) and P_2 (located within the Rach Tram estuary). Notably, the eastern sector of the Rach Tram estuary (P_3, P_4) demonstrates heightened susceptibility to pollutants during southwest monsoon conditions, while the western segment of the estuary (P_5, P_6, P_7, and P_8) experiences pollutant influence under northeast monsoon condition.

Given the discharge source's proximity of approximately 0.8 km from the estuary, pollutants that are carried rapidly disperse within the marine environment. Consequently, pollutant concentrations at sites along both the Eastern and Western banks of the Rach Tram Estuary generally register lower values than those present within the river itself.

The concentration shift chart in scenario 1 illustrates that within approximately 3 hours, the pollutant concentration extends to position P_1 and P_2. Subsequently, after around 7 hours, this spread encompasses location beyond the estuary, reaching into the open sea. During periods of high tide, the pollutants tend to retreat back into the river due to the influence of tidal currents, causing areas located 2.5 km upstream from the Rach Tram River's discharge point to be susceptible to pollutant propagation.

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