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Research Article

Assessment of water environmental carrying capacity of Thuy Trieu lagoon, Cam Ranh, Khanh Hoa

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Abstract: In recent years, the socio-economic development of two districts of Cam Lam and Cam Ranh city of Khanh Hoa province has taken place strongly. This process has affected the environment of Thuy Trieu lagoon (TTL), leading to the need to assess the lagoon water environmental carrying capacity (LECC). Based on survey data in the years 2019–2021, this study has the objective of assessing the environmental capacity of the Thuy Trieu lagoon. Three substances are selected: Ammonia, Phosphate, and Nitrate. In this study, we use a MIKE 3 model with a Hydrodynamic module (HD) combined with a 3D numerical lab for ecological modeling (ECOLab), then extract the results and calculate the environmental carrying capacity load for the Thuy Trieu lagoon in the wet and dry seasons. The results showed that in the dry season, the residual carrying capacity of the water body $LECC_{RM}$ of substances such as Ammonia is 104.81 tons/month, Phosphate 193.18 tons/month, and Nitrate 2,294.91 tons/month. During the wet season, the $LECC_{RM}$ capacity in the water body also increased compared to the dry season with the $LECC_{RM}$ values of the following substances: Ammonium 165.33 tons/month, Phosphate 311.41 tons/month, and Nitrate 3,629.60 tons/month. This result complements the results already done, helping to have a more scientific basis for lagoon management and planning.

Keywords: Lagoon water quality; 3D hydrodynamic model; Ecological model; LOICZ; Thuy Trieu lagoon.

1. Introduction

Vietnam's coast has a total sea surface area of nearly 4,000 km^2 with all three types of water bodies, typically bays (gulf, bay, bight), estuary, and coastal lagoons [1]. The problem of lagoon pollution and marine environmental carrying capacity posed a science for the first time in [2]. From the initial concepts of ecological carrying capacity and environmental capacity assessment methods, up to now, related concepts and methods of assessing marine environmental capacity have become more and more complete. Environmental capacity helps to define sustainable limits for sustainable development action; rationally distribute activities taking place on and around water bodies to achieve the highest economic efficiency and maintain environmental quality within allowable limits and develop solutions to maintain and restore environmental capacity [3]. This is not only a theoretical development of marine environmental capacity but is mainly based on the practice of marine environmental pollution occurring in many parts of the world.

According to research by [4], most of the coastal areas worldwide have been ruined by pollution. As a result, coastal fisheries and marine-related industries are significantly affected [5]. In order to sustainably manage the coast and protect fishery resources, pollution of the aquatic environment needs to be controlled. In the control of marine pollution, a series of programs such as the total daily maximum tonnage of the United States and the European Framework of Marine Strategic Indicators, the carrying capacity of the marine environment for pollutants must be estimated because it is important for coastal water management, as well as sustainable use of coastal areas [6–8]. From there, the discharge, transport, and transformation of pollutants must be analyzed and their effects assessed on the respective ecosystems [5]. To carry out this analysis and assessment, water quality modeling can make a powerful contribution to the necessary scientific basis of coastal zone management [9–10].

Increasing population density, and rapid developing socio-economic in the past centuries have led to increased discharge of pollutants from the landmass into these coastal seawaters [11–13]. These coastal environmental problems are mostly related to inland inputs, which are recognized to contribute to more than 75% of marine pollutants [14–15]. Therefore, it is very important to identify and estimate the pollutant load on land flowing to the coastal area and this is also the basis for pollution control and reduction. The US National Oceanic Development Policy and the European Union (EU) maritime strategy emphasize the use of integrated ecosystem-based management to maintain a healthy marine environment. China has established a "monitoring and forecasting system of natural resource-environmental capacity" based on land and sea assessment to promote ecological civilization-building [7].

Since the late 1970s, many research efforts have been made to estimate the terrestrial pollutant discharge to coastal areas around the world [16–17]. Based on the research findings, a range of policy instruments, such as the Total Maximum Daily Load (TMDL) program, the Best Management Practices, the Directive the European Water Framework Directive, etc., has been adopted to control soil pollution in developed countries such as the United States, Canada and the countries of the European Union.

In recent years, the process of socio-economic development of the central coastal region, including two districts of Cam Lam and Cam Ranh city of Khanh Hoa province, has firmly increased pressure on the environment, including the Thuy Trieu lagoon. Against that background, several studies have been conducted to assess marine environmental capacity (EC). The first study on the marine capacity in Vietnam was carried out in 2001 [18]. Recent years have been followed by studies [3, 19 – 21]. In that context, research has been carried out for this area, especially [19] presented the results of the environmental capacity assessment of Thuy Trieu lagoon from 2011 to 2012. However, this work is only based on monitoring data from some periods to estimate the average concentration for the whole lagoon. This leads to a non-accurate calculation. Therefore, our team continues to study this area by adopting a different approach, namely modelization. The modeling results, in the opinion of the authors, will give the average concentration over the entire lagoon more accurate, especially the model that has passed the calibration and verification steps. Therefore, it can be said that this study will supplement the results already done, and provide a better scientific basis for the management and planning of the lagoon.

Although environmental capacity has been considered for many coastal areas, when applied to specific coastal lagoons, it is still necessary to consider the possibility of communication between the lagoon and the open sea, namely the effects of hydrodynamic factors on LECC must be noticed. In this study, the authors use the method in [21] to calculate the LECC for the selected water body. The object of the study is Thuy Trieu lagoon, Khanh Hoa province. The steps in this study include hydrodynamic calculation, lagoon water quality assessment, and LECC calculation with clarification of semi-enclosed factors.

2. Materials and methodology

2.1. Study area

The scope of the study is the Thuy Trieu lagoon area, in Cam Lam district and Cam Ranh city. This is a prison lagoon and it seems that there is only water exchange through Cam Ranh

Bay, so the study extends to Cam Ranh Bay and creates an open boundary at the mouth of the bay (Figure 1).

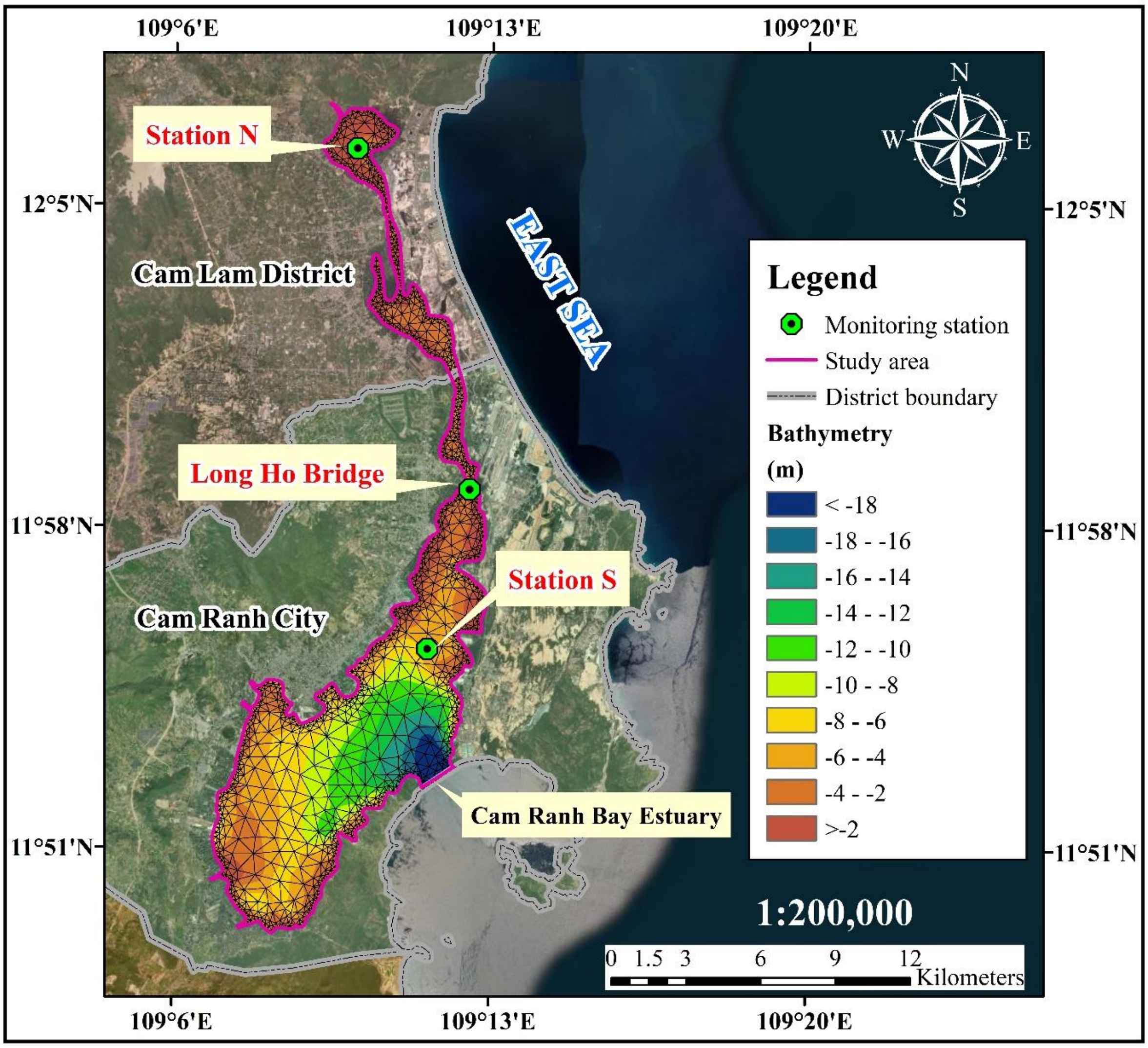


Figure 1. The study area, computation mesh, bathymetry, and monitoring stations.

2.2. Data

2.2.1. Bathymetry data

Bathymetry data Thuy Trieu Lagoon (from the top of Thuy Trieu Lagoon to Long Ho Bridge – the contiguous position between Thuy Trieu Lagoon and Cam Ranh Bay) in this study are measured data provided by Khanh Hoa Environmental and Resource Monitoring Cente. The bathymetry of Cam Ranh Bay is taken from General Bathymetric Chart of the Oceans (GEBCO) data. The computation mesh is set up with 2,195 nodes and 3,317 triangular elements, the minimum allowed angle is 26^o.

2.2.2. Meteorological data

The study took into account the area's meteorology. These data are extracted from Danish Hydraulics Institute (DHI) global data. Velocity (m/s) and wind direction (degrees) data are the time series from January 1, 2019 to December 31, 2020, and the time step is 1 hour. Besides, the evaporation data are calculated as an average annual value to calculate the water retention time.

2.2.3. Hydrological data

The water level boundary data at the inlet of Cam Ranh Bay was established with tidal data extracted from the MIKE Toolbox. Water level data measured at Long Ho Bridge station (Fig. 1) from January 1, 2019 to December 31, 2020, the time step 1 hour is used to calibrate – validate the Hydrodynamic (HD) module.

In addition, annual average rainfall data is collected to calculate the retention time of water.

2.2.4. Measured water quality data

Measured water quality data at Station N, Station S, and Station M locations (Figure 1) is provided by Khanh Hoa Environment and Natural Resources Monitoring Center. The pollutants noted are BOD_5, DO, NH_4^+, NO_3^-, PO_4^{3-}, Ecoli, and Coliforms. The value of the data is the average of the month in 2020. Data at Station S and Station M are used to calibrate the ECOLab model.

In this paper, the water quality data from the model is compared with the National Water Quality Standard (NWQS) from QCVN 10-MT:2015/BTNMT (National technical regulation on marine water quality – NMWQ) and QCVN 08-MT:2015/BTNMT (National technical regulation on surface water quality – NSWQ) (Table 1).

Table 1. National Water Quality Standard (Unit: mg/L).

Parameter	NWQS		
	NMWQ	NSWQ	
	Aquaculture areas, aquatic conservation	A1	A2
DO	≥ 5	≥ 6	≥ 5
BOD_5	-	4	6
Ammonia	0.1	0.3	0.3
Nitrate	-	2	5
Phosphate	0.2	0.1	0.2

2.2.5. Land-based pollution source data

In this study, we pay attention to 3 sources of waste collected from documents of the Khanh Hoa Center for Natural Resources and Environment Monitoring, in which industrial wastewater is Khanh Hoa sugar factory (NMD), domestic wastewater is residential near Cam Hai bridge (T1) and residential near sugar factory (C5). Detailed information about waste sources is shown in Table 2 below.

Table 2. Land-based pollution source information.

Name	X	Y	Discharge (m^3/s)	DO	NH_4^+	NO_3^-	BOD_5	PO_4^{3-}	Total P	Coliform
NMD	303050	1330967	0.105	5.73	0.35	1.25	23.08	0.96	2.23	7000.00
T1	301657	1335928	0.014	5.73	0.18	0.24	6.80	0.04	0.39	9300.00
C5	302648	1331095	0.014	5.73	0.21	0.28	17.72	1.29	2.91	6800.00

2.3. Methodology

In this study, our team approaches the calibrated and verified MIKE 3 with hydrodynamic and ECO Lab modules. Then, simulate advection-dispersion. Next, extract values from the model such as lagoon volume, flow velocity, area, and discharge,… combined with meteorological data such as precipitation and evaporation to calculate the water retention time using the LOICZ model. Finally, extract the concentration of substances from the model results combined with NWQS, and lagoon volume to calculate LECC. This process is shown in Figure 2.

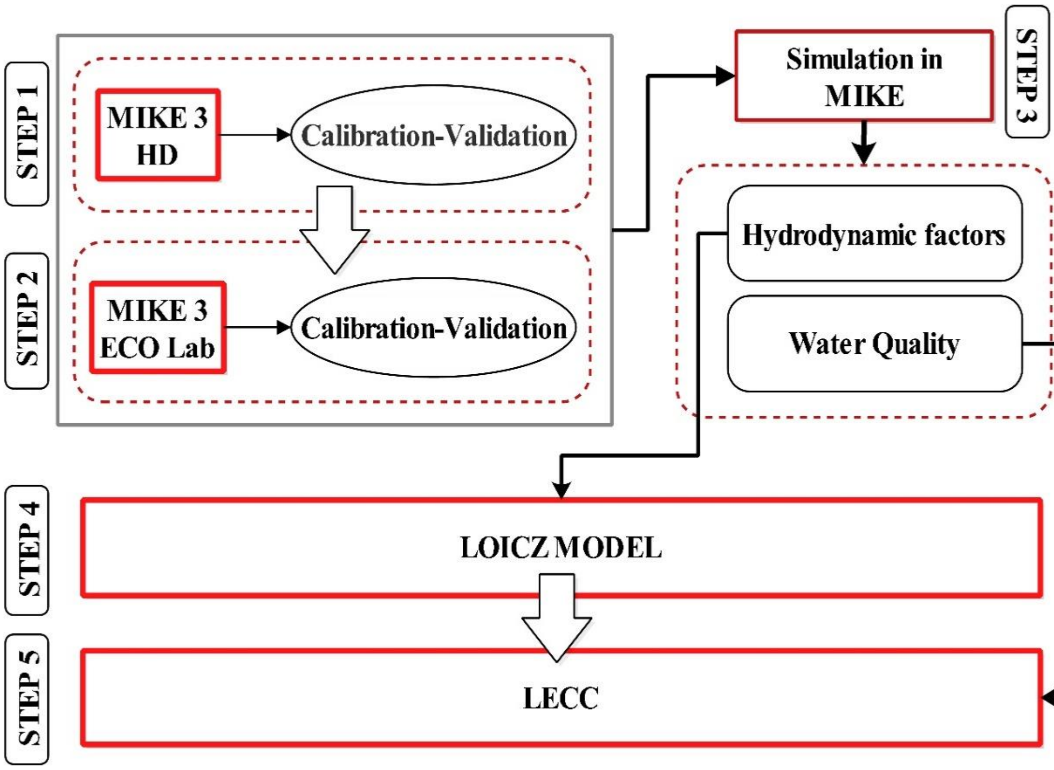


Figure 2. The flow chart of study structure.

2.3.1. Hydrodynamic model

MIKE 3 HD developed by DHI is used to simulate the flow and tidal regime [22]. This model is built from 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

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

The two horizontal momentum equations for the x- and y- components respectively as below:

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

$$\frac{\partial v}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}=fu-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{g}{\rho_0}\int_z^\eta\frac{\partial \rho}{\partial y}-\frac{1}{\rho_0 h}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+F_v+\frac{\partial}{\partial z}\left(v_t\frac{\partial v}{\partial z}\right)+v_sS \tag{3}$$

$$F_u=\frac{\partial}{\partial x}\left(2A\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(2A\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right) \tag{4}$$

$$F_v=\frac{\partial}{\partial y}\left(2A\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial x}\left(2A\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right) \tag{5}$$

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= η+d is the total water depth; u, v and w are the velocity components in the x, y and z direction; f=2Ω sinΦ is the Coriolis parameter (Ω is the angular rate of revolution and ϕ the geographic latitude); 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; ν_t is the vertical turbulent (or eddy) viscosity; p_a is the atmospheric pressure; ρ_0 is the reference density of water. S is the magnitude of the discharge due to point sources and (u_s v_s) is the velocity by which the water is discharged into the ambient water. F_u, F_v are horizontal stress terms, A is horizontal viscous turbulence. The MIKE 3 HD module allows to calibrate two main parameters, namely the viscosity coefficient (eddy viscosity, ν, m^2/s) and the roughness height (roughness height, k_s, m) [22–25].

2.3.2. Ecological model

The biochemically coupled advection–diffusion model was developed to evaluate the physical–biological interactions in estuarine tropical ecosystems on nutrient and oxygen cycling:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\frac{\partial wC}{\partial z}=\frac{\partial}{\partial x}\left(K_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right)+F_{Ecolab}(C,t) \quad (6)$$

The compartments of the ecological model are dissolved oxygen (DO), biological oxygen demand (BOD), Ammonia (NH_4^+), and Phosphate (PO_4^{3-}) for the water quality factors. The variation concentrations at a given time in the ecological model is described by the equation (7-10).

$$\frac{dDO}{dt}=K_2(C_s-DO)-K_3.BOD.\theta_3^{(T-20)}.\frac{DO}{DO+[HS\_BOD]}-K_4.NH_3.\theta_4^{(T-20)}.\frac{DO}{DO+[HS\_nitr]} \quad (7)$$
$$+P_{max}.F_1(H).\cos 2\pi(\tau/\alpha).\theta_1^{(T-20)}-R_1.F_1(H).\theta_1^{(T-20)}-R_2.\theta_2^{(T-20)}-SOD$$

$$\frac{dBOD}{dt}=-K_3.BOD.\theta_3^{(T-20)}.\frac{DO}{DO+HS\_BOD} \quad (8)$$

$$\frac{dNH_4^+}{dt}=Y_{BOD}.K_3.BOD.\theta_3^{(T-20)}.\frac{DO}{DO+HS\_BOD}-K_4.NH_3.\theta_4^{(T-20)}-UN_p.(P-R_1.\theta_1^{(T-20)})$$
$$-UN_b.K_3.BOD.\theta_3^{(T-20)}.\frac{NH_3}{NH_3+HS\_NH_3}+UN_p.R_2.\theta_2^{(T-20)} \quad (9)$$

$$\frac{dPO_4}{dt}=Y_2.K_3.BOD.\theta_3^{(T-20)}.\frac{PO_4}{PO_4+HS\_PO_4}-UP_p.(P-R_1.\theta_1^{(T-20)})$$
$$-UP_b.K_3.BOD.\theta_3^{(T-20)}.\frac{PO_4}{PO_4+HS\_PO_4}-UP_p.R_2.\theta_2^{(T-20)} \quad (10)$$

The coefficients in equations (1) to (10) are shown in Table 3.

Table 3. Coefficients in the Ecological model.

No.	Parameter	Unit
1	Oxygen Processes: Respiration of animals and plants ($R_1 = R_2$)	(/d)
2	Oxygen Processes: Respiration temperature coefficient (q_1) = (q_2)	dimensionless
3	Sediment processes: Sediment oxygen demand (SOD)	g/m^2/day
4	Nitrogen Content: Ratio of ammonia released at BOD decay (Y_{BOD})	gNH_4/gBOD
5	Nitrogen Content: Uptake of ammonia in plants (UN_p)	Dimensionless
6	Nitrogen Content: Uptake of ammonia in bacteria (UN_b)	Dimensionless

No.	Parameter	Unit
7	Nitrification: Ammonia decay rate at 20 deg Celcius (K_4)	(/d)
8	Nitrification: Temperature coefficient for nitrification (q_4)	Dimensionless
9	Denitrification: Half saturation constant (HS_denitr = HS_PO_4 = HS_NH_3 = HS_nitr)	mg/l
10	Denitrification: Denitrification rate, conversion of nitrate into free nitrogen N_2 (K_6)	1/day
11	Denitrification: Temperature coefficient for denitrification (q_6)	Dimensionless
12	Coliforms: 1. Order decay Faecal coliforms (K_{dF})	(/d)
13	Coliforms: Arrhenius temperature coefficient (q)	Dimensionless
14	Phosphorus content: Ratio of phosphorus released at BOD decay (Y_2)	gP/gBOD
15	Phosphorus content: Uptake of P in plants (UP_p)	Dimensionless
16	Degradation: 1. order decay rate at 20 deg. C (K_3)	(/d)
17	Degradation: Temperature coefficient for decay rate (q_3)	Dimensionless
18	Degradation: Half-saturation oxygen concentration (HS_BOD)	mg/l

2.3.3. The Land Ocean Interactions in the Coastal Zone (LOICZ) model

This study used the wide model applied in coastal water bodies - the LOICZ to estimate the retention time of water, material balance, and nutrient status [25–27]. The retention time τ of water in a water body is expressed in equation (11):

$$\tau = \frac{V_{Sys}}{\left(V_X + |V_R|\right)} \quad (11)$$

where V_{sys} is bay volume, V_X is the exchange flow between the system and the sea, V_R is a residual flow to the sea [25].

2.3.4. LECC model

In this study, as applied to TTL, based on volumetric data and water retention time combined with data on pollutant content in water bodies and national water quality standards, the LECC is calculated as follows:

$$LECC = V_{sys}\left(1 + 1/\tau\right) \times \left(C_{ST} - C_{CR}\right) \quad (12)$$

where C_{CR} is the average concentration of pollutants, which is extracted from the results of running the eco-hydrodynamic model, considering the water body's self-cleaning process; C_{ST} is the allowable concentration of pollutants in National Water Quality Standards (NWQS); V_{sys} is the average water body volume in wet and dry seasons [19, 21].

$LECC_{PT}$ is potential LECC, the threshold amount of a pollutant that the water body, can hold according to the norm; τ is an important parameter that considers the water exchange between the Thuy Trieu lagoon and the open sea determined according to the LOICZ model. $LECC_{CR}$ is the current amount of a pollutant that the water body can hold, and C_{CR} is obtained from the seasonal average modelling results. $LECC_{RM}$ is the remaining amount of a pollutant that the water body can accept with that pollutant, in other words, $LECC_{RM}$ is the residual amount of pollutants that can be accepted by the water body. $LECC_{AU}$ is the residual safe threshold amount of pollutants that can be accepted by the water body, in other words, $LECC_{AU}$ is the remaining safe amount of a pollutant that the water body can accept.

2.4. Method to evaluate model accuracy

To evaluate the reliability of the model, the study uses the following four statistical criteria to evaluate: R^2, NSE, RSR, and PBIAS. R^2 is calculated directly from Excel, other formulas (13) to (15) include:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Q_i^{obs} - \bar{Q}\right)^2} \quad (13)$$

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\sqrt{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(Q_i^{obs} - \bar{Q}\right)^2}} \quad (14)$$

$$\mathrm{PBIAS\%} = \frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right) \times 100}{\sum_{i=1}^{n}\left(Q_i^{obs}\right)} \quad (15)$$

where Q_i^{obs} is the measured value, Q_i^{sim} is the value from the model, and $\bar{Q}$ is the measured average value.

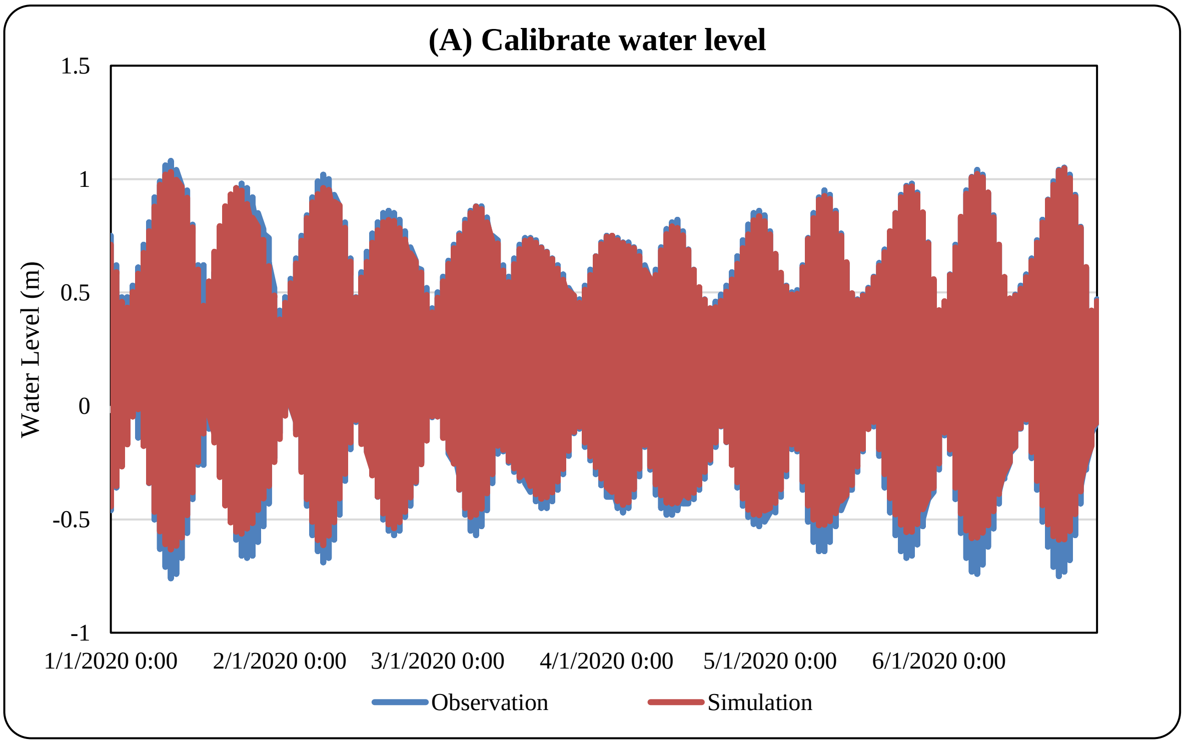
2.5. Model setup

2.5.1. Module HD

The Hydrodynamic model is set from January 1, 2020 to December 31, 2020, with a time step of 30 seconds. The viscosity coefficient with eddy type according to the Smagorinsky formula is 0.28, roughness coefficient with the Roughness height formula is 0.05m. The wind is also noted in the model. The module calibration time is selected from 1 January 2020 to 30 June 2020, with a time step of 1 hour at Long Ho Bridge station. Similarly, the validation period is from 1 July 2020 to 31 December 2020. The results of calibration and validation show that the water level data from the simulation and the measurements have a very good correlation for all four statistical criteria. This proves that the simulated Hydrodynamic model meets the requirements for simulation (Table 4).

Table 4. Water level correlation between model and measurement.

	R^2	**NSE**	**RSR**	**PBIAS%**
Calibration	0.976	0.974	0.162	1.388
Validation	0.983	0.980	0.140	0.220



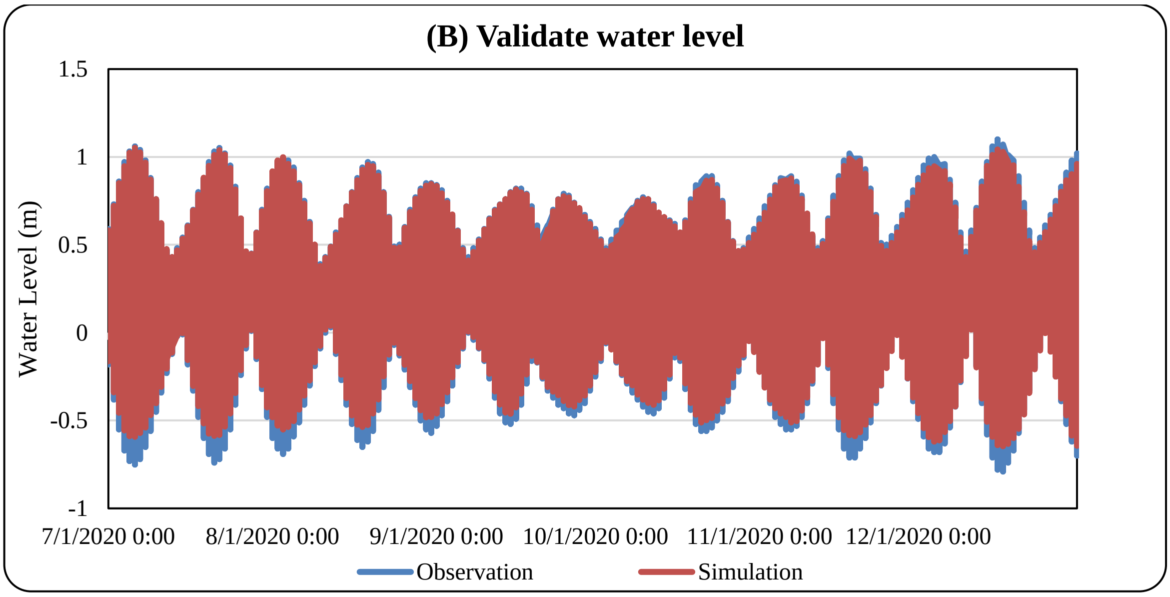


Figure 3. Water level between model and real measured (A) calibration (B) validation.

2.5.2. Module ECO Lab

The ECO Lab module is set up based on the calibrated HD module. Set up time is 1 year–2020, water quality parameters of boundary, initial, and discharge source are included in the model. Other parameters in ECOLab are set to default and adjusted gradually. The ECO Lab model used is MIKE WQ Level 4 and Coli + P. The dispersion coefficient is used according to the Scaled Eddy Viscosity formula, with the horizontal diffusion coefficient being 1, and the vertical being 0.01 (m^2/s). The set of parameters after calibrating is shown in Table 5. The comparison of the measured concentration and the simulation is shown in Table 6. The comparison results show that at Station S, 89.7% of the data has an accuracy of > 0.5, and Station M has 64.1% data with an accuracy of > 0.5 (Table 6). Since the data provided is a monthly average, only observed once a month, and taken as a representative of the month, it is difficult to correlate with the model.

Table 5. ECOLab parameter datasets applied in this model.

No.	Description	Value	Unit
1	Temperature: Latitude		
2	Temperature: Maximum absorbed solar radiation	4992	(/d)
3	Temperature: Displacement of solar radiation max. from 12 pm	0	hours
4	Temperature: Emitted heat radiation	1608	(/d)
5	Oxygen Processes: No. of reaeration expression	4	dimensionless
6	Oxygen Processes: Reaeration temperature coefficient	1.02	dimensionless
7	Oxygen Processes: Respiration of animals and plants	3	(/d)
8	Oxygen Processes: Respiration temperature coefficient	1.05	dimensionless
9	Oxygen Processes: Max. oxygen production by photosynthesis	2	(/d)
10	Oxygen Processes: Production/respiration per m^2 (=1) or per m^3 (=2)	1	
11	Degradation: 1. order decay rate at 20 deg. C	0.1	(/d)
12	Degradation: Temperature coefficient for decay rate	1	dimensionless
13	Degradation: Half-saturation oxygen concentration	2	mg/l
14	Oxygen Processes: Own #1 Reaeration constant	1	(/d)
15	Oxygen Processes: Own #1 Exponent, flow velocity	0	dimensionless
16	Oxygen Processes: Own #1 Exponent, water depth	0	dimensionless
17	Oxygen Processes: Own #1 Exponent, river slope	0	dimensionless
18	Oxygen Processes: Own #2 Reaeration constant	1	(/d)

No.	Description	Value	Unit
19	Oxygen Processes: Own #2 Exponent, flow velocity	0	dimensionless
20	Oxygen Processes: Own #2 Exponent, flow velocity	0	dimensionless
21	Oxygen Processes: Own #2 Exponent, river slope	0	dimensionless
22	Oxygen Processes: Own #3 Reaeration constant	1	(/d)
23	Oxygen Processes: Own #3 Exponent, flow velocity	0	dimensionless
24	Oxygen Processes: Own #3 Exponent, flow velocity	0	dimensionless
25	Oxygen Processes: Own #3 Exponent, river slope	0	dimensionless
26	Sediment processes: Sediment oxygen demand	2	g/m^2/day
27	Sediment processes: Temperature coefficient SOD	1	Dimensionless
28	Sediment processes: Resuspension of organic matter	0.5	g/m^2/day
29	Sediment processes: sedimentation rate for organic matter	0.8	m/day
30	Sediment processes: Critical flow velocity	1	m/s
31	Nitrogen Content: Ratio of ammonia released at BOD decay	0.2	gNH_4/gBOD
32	Nitrogen Content: Uptake of ammonia in plants	0.2	dimensionless
33	Nitrogen Content: Uptake of ammonia in bacteria	0.1	dimensionless
34	Nitrification: Reaction order 1 = first order process 2 = half order process	1	dimensionless
35	Nitrification: Ammonia decay rate at 20 deg Celcius	0.5	(/d)
36	Nitrification: Temperature coefficient for nitrification	1.13	dimensionless
37	Denitrification: Oxygen demand by nitrification	4.47	gO_2/gHN_4
38	Denitrification: Half saturation constant	0.5	mg/l
39	Denitrification: Reaction order 1 = first order process 2 = half order process	1	dimensionless
40	Denitrification: Denitrification rate, conversion of nitrate into free nitrogen N_2	0.1	1/day
41	Denitrification: Temperature coefficient for denitrification	1.2	dimensionless
42	Coliforms: 1. Order decay Fecal coliforms	0.2	(/d)
43	Coliforms: 1. Order decay Total coliforms	0.3	(/d)
44	Coliforms: Arrhenius temperature coefficient	1.09	dimensionless
45	Coliforms: Salinity coefficient of decay rate	1.01	dimensionless
46	Coliforms: Light coefficient of decay rate	1	dimensionless
47	Coliforms: Light Extinction Coefficient	1	1/m
48	Phosphorus content: Ratio of phosphorus released at BOD decay	0.01	gP/gBOD
49	Phosphorus content: Uptake of P in plants	0.009	dimensionless
50	Phosphorus exchange with bed: Resuspension of particulate phosphorus	0.5	g/m^2/day
51	Phosphorus exchange with bed: Deposition of particulate phosphorus	0.8	m/day
52	Phosphorus exchange with bed: Critical velocity of flow	1	m/s
53	Phosphorus processes: Decay constant for particulate phosphorus	0.1	(/d)
54	Phosphorus processes: Temperature coefficient for decay	1	dimensionless
55	Phosphorus processes: Formation constant for particulate phosphorus	0.1	(/d)
56	Phosphorus processes: Temperature coefficient for formation	1	dimensionless

Table 6. Comparison of the measured and modeled concentration outcomes.

		Station S			Station M		
	Time	**Observation**	**Simulation**	**Accuracy**	**Observation**	**Simulation**	**Accuracy**
DO	Jan-20	5.9000	5.2476	0.8894	6.1000	4.1351	0.6779
	Feb-20	6.2000	5.1659	0.8332	5.7000	3.9923	0.7004
	Mar-20	6.3000	5.3073	0.8424	5.8000	3.9906	0.6880
	Apr-20	6.2000	5.0487	0.8143	6.4000	3.9213	0.6127
	May-20	6.3000	5.4326	0.8623	5.3000	3.4940	0.6592
	Jun-20	5.7000	5.6636	0.9936	5.9000	3.3585	0.5692
	Jul-20	5.8000	5.7289	0.9877	6.0000	3.4604	0.5767
	Aug-20	5.7000	5.8867	0.9683	6.0000	3.5476	0.5913
	Sep-20	5.9000	6.0362	0.9774	5.7000	3.8990	0.6840
	Oct-20	6.0000	5.8649	0.9775	6.2000	4.0122	0.6471

		Station S			Station M		
	Time	**Observation**	**Simulation**	**Accuracy**	**Observation**	**Simulation**	**Accuracy**
	Nov-20	5.8000	5.4402	0.9380	5.1000	4.1449	0.8127
	Dec-20	5.0000	5.2640	0.9499	4.6000	4.0684	0.8844
Ammonium	Jan-20	0.0200	0.0251	0.7957	-	-	-
	Feb-20	0.0330	0.0237	0.7167	-	-	-
Nitrate	Feb-20	-	-	-	0.0200	0.0284	0.7045
	May-20	0.0260	0.0427	0.6085	0.0220	0.0289	0.7617
	Jun-20	0.0540	0.0364	0.6734	0.0230	0.0357	0.6450
	Jul-20	0.0260	0.0366	0.7096	-	-	-
	Aug-20	0.0260	0.0260	0.9981	0.0220	0.0243	0.9045
	Sep-20	0.0420	0.0354	0.8433	-	-	-
	Oct-20	0.0500	0.0424	0.8487	-	-	-
	Nov-20	0.0470	0.0603	0.7791	0.0530	0.0270	0.5089
	Dec-20	0.0620	0.0690	0.8984	0.0490	0.0289	0.5892
BOD	Jan-20	3.1200	2.8048	0.8990	-	-	-
	Feb-20	3.9000	2.6245	0.6729	-	-	-
	Mar-20	3.3000	1.7853	0.5410	-	-	-
	Apr-20	3.3000	1.6542	0.5013	-	-	-
	Nov-20	3.3000	2.4562	0.7443	-	-	-
	Dec-20	3.3000	3.0596	0.9271	-	-	-
Phosphate	Jan-20	0.0320	0.0541	0.5911	-	-	-
	Feb-20	-	-	-	0.0300	0.0424	0.7072
	Mar-20	0.0590	0.0531	0.9002	0.0520	0.0427	0.8204
	Apr-20	0.0300	0.0504	0.5956	0.0400	0.0375	0.9381
	May-20	-	-	-	0.0300	0.0412	0.7276
	Jun-20	0.0270	0.0452	0.5967	-	-	-
	Jul-20	0.0230	0.0451	0.5094	-	-	-
	Aug-20	0.0270	0.0430	0.6274	0.0230	0.0367	0.6267
	Sep-20	0.0350	0.0446	0.7845	0.0320	0.0329	0.9731
	Oct-20	-	-	-	0.0200	0.0383	0.5225

2.6. Conceptual model

The model of integrating information and data with mathematical models (presented above is named LECC) LECC includes a database bank, a model bank shown above Figure 4. The database block consists of 7 components: meteorology; hydrology; oceanography; surface water quality, waste source; Tide Prediction of Height dataset, and Vietnamese standards; model bank block includes 4 models: hydraulic, water quality model, residual time model, load calculation model. The LECC operation is carried out as follows: First, calibrate and verify the hydrological model; Second, the hydraulic model and water quality model simulate the concentration of selected substances, at the same time, in this step, NWQS block on water quality standards and results Retention time calculation results are performed to move to step 3; Third, calculate $LECC_{PT}$, $LECC_{CR}$, $LECC_{RM}$, and $LECC_{AU}$; Step four, verify LECC calculation results are transferred back to Step 2 to test whether when adding a calculated load $LECC_{RM}$ or $LECC_{AU}$, the water quality in the study area meets NWQS. The results outputted by LECC include flow simulation results in 3 layers, results on water quality modeling in 3 floors, $LECC_{RM}$ and $LECC_{AU}$ capacity calculation results Figure 4.

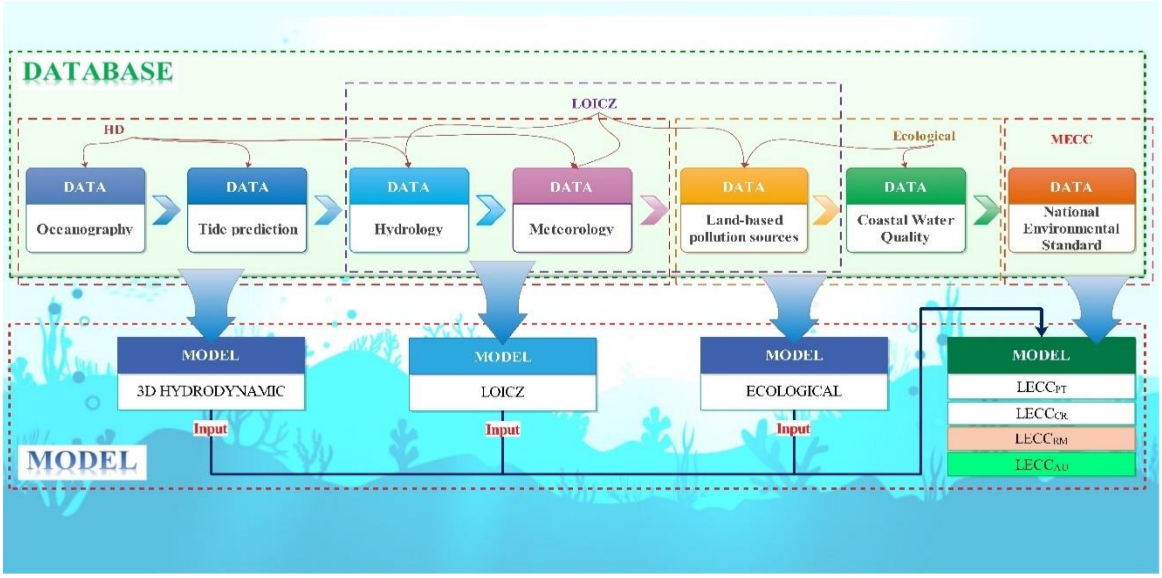


Figure 4. Conceptual model LECC.

3. Results and discussion

3.1. Hydrodynamic simulation

The hydraulic regime of Thuy Trieu lagoon is affected by the tides. The division of Thuy Trieu lagoon into 2 parts that can be clearly seen based on the water level. The North region from Thuy Trieu Lagoon Peak to Moi Bridge belongs to the commune and the South region from Moi Bridge to Long Ho Bridge. The study runs a hydrodynamic for the whole of 2020; Figure 4 represents April (dry season) and November (wet season). The water level in the wet season is higher than that in the dry season, the peak and the bottom of the tide in the wet season are 0.5 m different from that in the dry season. This shows that in the wet season, the water level in the lagoon increases rapidly due to the inflow of Cam Ranh Bay, presented in Figure 5.

In general, the flow velocity in the lagoon does not change much because it is a stagnant lagoon that only exchanges water through Cam Ranh Bay, so it is less affected by hydrodynamic factors from other regions. The flow velocity in the lagoon ranges from 0 to 0.15 m/s, the velocity is small at the shoreline and higher in the middle of the lagoon. Strong currents >0.4 m/s occur at the waists connecting the regions (at Moi Bridge and Long Ho Bridge) (Figure 6).

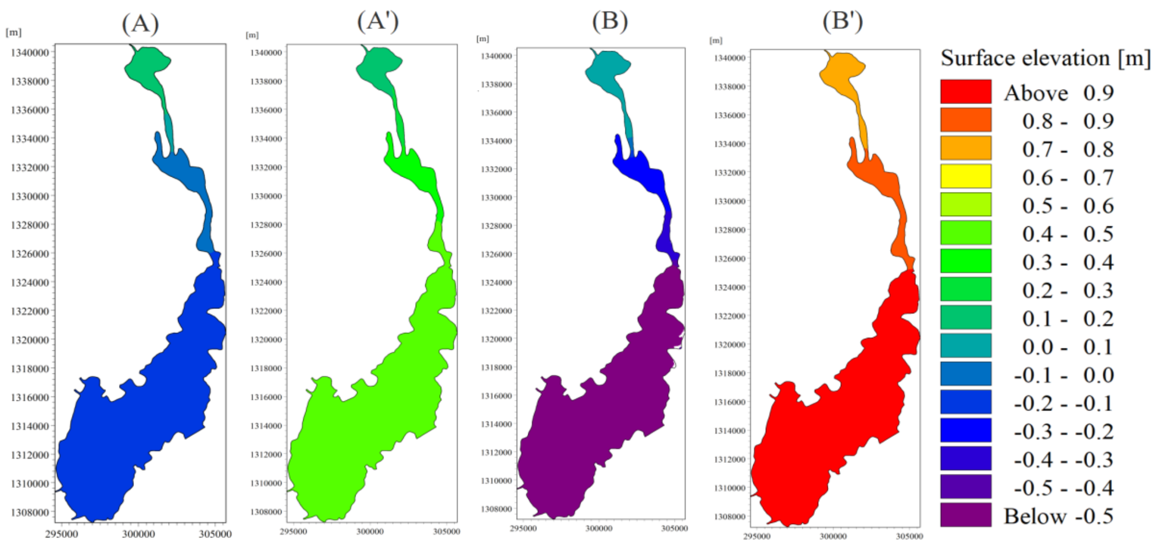


Figure 5. The water level at (A) the low tide, and (A') high tide in the dry season; (B) low tide, and (B') high tide in the wet season.

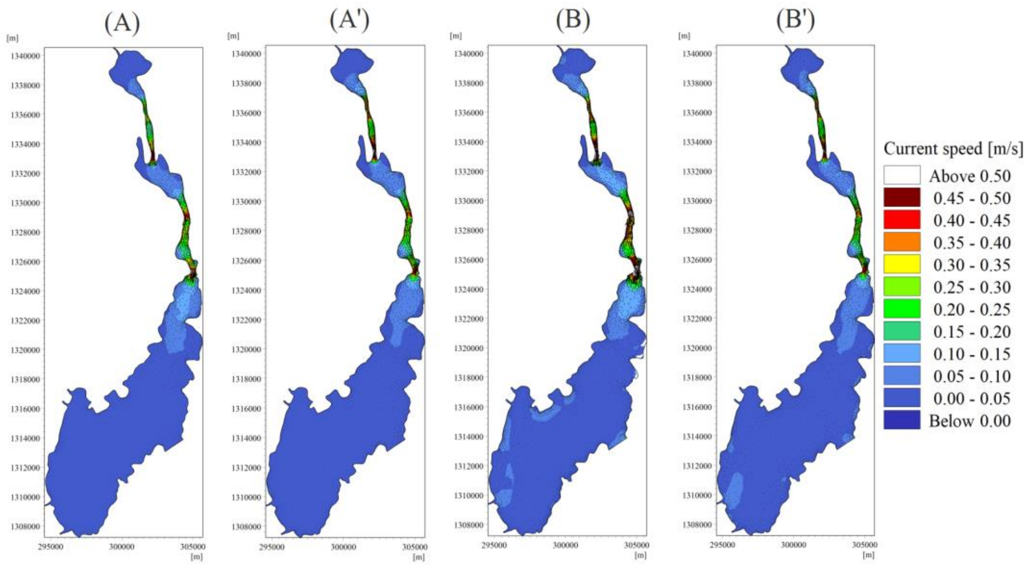


Figure 6. Current velocity at (A) low tide, (A') high tide in the dry season; (B) low tide, (B') high tide in the wet season.

3.2. Water quality modelling

The results of the substance advection-dispersion simulation for 2020 indicate that most of the parameters meet NWQS (Table 1) except for Ammonia not meet the NMWQ (the limit for it is ≤ 0.1 mg/l), but this parameter meets the NSWQ (the limit for it is ≤ 0.3 mg/l). This can be explained as the monitoring results of all parameters that meet NWQS, the model is calibrated by this data, so most substances meet NWQS.

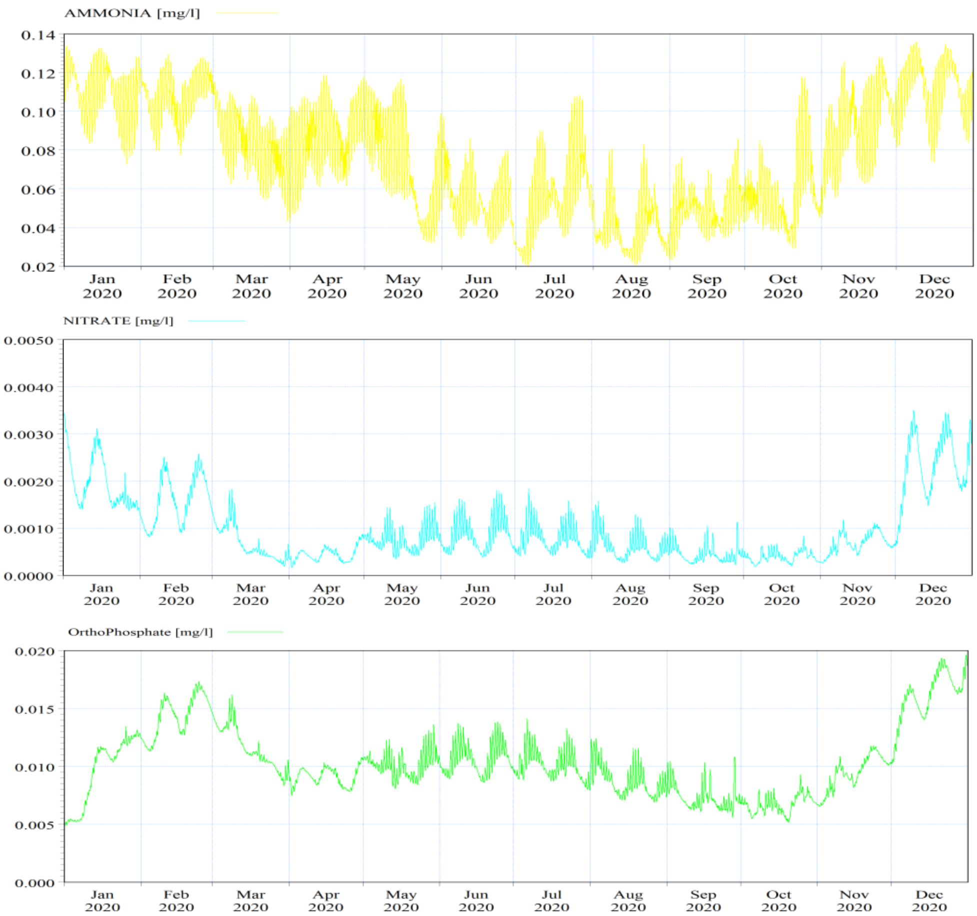


Figure 7. Diagrams of NH_4^+, NO_3^-, and PO_4^{3-} changes in 2020 of TTL.

In terms of concentration distribution, most of the concentrations in the TTL did not change much, only increased during high tide and increased sharply in the wet season, with pollution from Cam Ranh Bay pushed in plus pollution from the South of the Lagoon to the North of the Lagoon and leaving it there, Figure 7. This is proven when considering the concentration of substances at the top of the Thuy Trieu Lagoon, they increase in the middle of the wet season, increase from November to February next year and decrease gradually from March, then fluctuate stably from April to October.

3.3. Retention time

The method of assessing water exchange capacity by the LOICZ model calculates the retention time of the tidal lagoon area as 28.11 days for the dry season and 14.01 days for the wet season (Table 7).

Table 7. The results of the calculation for the retention time.

	Unit	**Wet**	**Dry**
Precipitation (V_p)	$10^6 m^3$/month	7.9510	3.8960
Evaporation (V_e)	$10^6 m^3$/month	0.0005	0.0013
River (V_q)	$10^6 m^3$/month	0	0
Groundwater flow volume (V_g)	$10^6 m^3$/month	0	0
Other sources (V_o)	$10^6 m^3$/month	0.1328	0.1328
Area	$10^6 m^2$	96.9498	
System volume (V_{sys})	$10^6 m^3$	566.3063	566.1567
Residual flow volume (V_r)	$10^6 m^3$/month	–8.0833	–4.0275
System salinity (S_{sys})	‰	26.4	26.4
Oceanic salinity (S_{ocean})	‰	33	33
The salinity flux (V_x)	$10^6 m^3$/month	32.3331	16.1101
The retention time (τ)	Day	14.0118	28.1143

3.4. LECC calculation

The results of calculating capacity are shown in Table 8 and Table 9. Note that the dry season of the study area lasts from January to August and the wet season is mainly from September to December.

Table 8. The load capacity of Thuy Trieu lagoon in the dry season.

Pollutant	**$LECC_{PT}$ (ton/month)**	**$LECC_{CR}$ (ton/month)**	**$LECC_{RM}$ (ton/month)**	**$LECC_{AU}$ (ton/month)**
Ammonia	115.01	10.21	104.81	70.30
Phosphate	230.03	36.85	193.18	124.17
Nitrate	2300.30	5.39	2294.91	1604.82

Table 9. The load capacity of Thuy Trieu lagoon in the wet season.

Pollutant	**$LECC_{PT}$ (ton/month)**	**$LECC_{CR}$ (ton/month)**	**$LECC_{RM}$ (ton/month)**	**$LECC_{AU}$ (ton/month)**
Ammonia	181.92	16.59	165.33	110.75
Phosphate	363.84	52.44	311.41	202.25
Nitrate	3638.43	8.83	3629.60	2538.07

From the simulation results, it is found that the considered that 2 indicators have concentrations that meet NMWQ and NSWQ except for Ammonia only meets the NSWQ, so the environmental capacity in this area is still high with Phosphate and Nitrate, and

Ammonia is the lowest. These are shown in Table 8 and Table 9. Specifically, during the dry season, the study area's volume is 566.1567 million m^3, so the remaining capacity of Ammonia, Phosphate, and Nitrate indicators is 104.81 tons/month, 193.18 tons/month, and 2,294.91 tons/month, respectively. For the wet season, the volume of the area increased by 0.1496 million m^3, so the remaining capacity of Ammonia, Phosphate, and Nitrate substances also increased, followed by 60.52 tons/month, 118.23 tons/month, and 1,334.69 tons/month, respectively.

3.5. Discussion

In the study [19] based on the observed data of the Thuy Trieu lagoon to calculate the load, this approach may lead to errors when choosing the average concentration of pollutants in the study water body C_{CR}. Meanwhile, this study is based on the method of using the MIKE 3 model to calculate the concentration of substances present in the area, then using the results of the load bearing model. There are also differences in the method of calculating the retention time between the two studies. At the time of implementation, the study [19] calculated the retention time to be 18.90 days for the dry season and 16.02 days for the wet season, while this study team calculated the retention time in the dry season to be 28.1143 days and in the dry season is 14.0118 days, this explains the difference in the relevant parameters in 2 different periods: 2011–2012 and 2019–2020 at present. At the same time, in the process of calculating the retention time for the area in the study of the team, only for the whole area of Thuy Trieu lagoon – Cam Ranh Bay, while the research team [19] divided into 3 areas: the peak area Thuy Trieu lagoon, Thuy Trieu lagoon estuary and Cam Ranh Bay.

There are also differences in the results of the calculation of the load between the two studies: based on the input data and the calculation results from the model, the Ammonium, Phosphate and Nitrate considered substances in this study are still capable of being considered. load capacity, > 70 tons/month, while in the study of [19], the indicators of Ammonium and Nitrate were close to the useful capacity, and the indicator of Phosphate reached the potential carrying capacity of the region.

4. Conclusion

Based on survey data, collected during 2019–2021, together with the socio-economic development plan in Thuy Trieu – Cam Ranh lagoon area, the article presents the results of the assessment of the environmental capacity of the lagoon. The research results showed that the water bodies are still capable of receiving wastewater containing Ammonium, Phosphate, and Nitrate substances in both dry and wet seasons. Specifically, in the dry season, the residual capacity of water bodies ($LECC_{RM}$) of substances such as Ammonium 104.81 tons/month, Phosphate 193.18 tons/month, Nitrate 2,294.91 tons/month. During the wet season, the volume of water bodies increased by 0.1496 million m^3 compared to the dry season, the total volume of the water body in the wet season was 566.3063 million m^3, resulting in an increase in the $LECC_{RM}$ in the water body compared to the dry season with the $LECC_{RM}$ values of the water bodies. Substances are as follows: Ammonia 165.33 tons/month, Phosphate 311.41 tons/month, and Nitrate 3,629.60 tons/month.

Since our team aims to use modeling to calculate the substance advection-dispersion and then extract the values to calculate LECC, it is easy to apply to other lagoons and bay areas if there is a full set of data for the model. The study makes it easier to assess when a new waste source appears to assess the impact of this source on the regional environmental capacity, by just adding the waste source and running the simulation. Thereby helping the manager make it easier to make decisions about whether this project will be implemented. This is an easy path for environmental managers in the future. The next research direction is to collect more information on water quality, and forecast pollution concentrations in the area to optimize the established model. Collect more waste source information and evaluate if this calculation is correct.

Author contribution statement: Conceived and designed the experiments; Analyzed and interpreted the data; contributed reagents, materials, analysis tools, or data; module HD calibration/validation: H.H.T.P.; Performed the experiments; contributed reagents, materials, analyzed and interpreted the data; running ECOLab and LECC models: D.H.T.L.T.; wrote the manuscript: L.T.B.

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