Environmental capacity assessment for Amoni and TSS in Dung Quat Bay, Viet Nam

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Abstract. Vietnam has a more than 3,260 km coastline. It discharges annually to the marine about 847 billion m³ of water and over 250 million tons of sediment, accompanied by a large amount of nutrients and pollutants. However, the general assessment problem environmental capacity and carrying capacity of water bodies are still not paid attention in. In this study, carrying out an assessment of environmental capacity in Dung Quat Bay where many economic activities are taking place and negatively impact on the coastal environment. The combination of calculating the environment capacity proposed by Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and tissue hydrodynamics and water quality modeling package Mike21 has conducted environmental capacity assessment according to two typical seasons of the study area. The results show that, in the dry season, if compared with the standards of aquaculture, aquatic conservation, NH₄⁺ is no longer able to bear the load; however, compared to water standards for beaches and water sports, NH₄⁺ still has the capacity to bear the load of 0.029 (ton/day) and 2,231 (tons/day) at low and high tide, respectively. With TSS, it can withstand about 7 tons to 370 tons per day corresponding to low tide and high tide in the dry season. Moreover, in the rainy season, NH₄⁺ is no longer able to bear the load in all cases; TSS also has environment capacity of about 160 (tons/day) at the low tide and 660 (tons/day) at the high tide.

1. Introduction
Environmental capacity was firstly used in the early twentieth century, which has been applied in many socio-economic fields so far [1]. Facing with the growing conflicts between socio-economic development and environmental protection, in 1986, the marine science specialist group [2] published the document “Environmental capacity. An approach to marine pollution prevention”, accordingly “Environmental capacity is a property of the environment and can be defined as used its ability to accommodate a particular activity or rate of activity (e.g. volume of discharge per unit time, quantity of minerals extracted per unit time) without unacceptable impact.” Definition of this capacity must be taken into account physical processes as dilution, dispersion, sedimentation and evaporation, as well as all chemical, biochemical and biological processes which lead to degradation or removal [2]. The concept of environmental capacity is the foundation for current interests in sustainable development, an environmental approach which identifies thresholds for economic growth and increase in human population. Subsustainable development calculates the carrying capacity of the environment based on the size of the population, the standard of living desired, the overall quality of life, the quantity and type of artifacts created, and the demand on energy and other resources [3].

From the initial concepts on environmental capacity and environmental capacity assessment
method developed by GESAMP, the relevant concepts and methods of environmental capacity assessment have been improved to date: corpses defining sustainable limits for sustainable development action; rationally distribute activities taking place in and around the water body to achieve the highest economic efficiency and maintain environmental quality within the limits and developing solutions in order to maintain and restore environmental capacity [4]. Hana et al [5] studied environmental capacity and proposed to determine environmental capacity method for Jiaozhou Bay, China, which receives wastewater from Qingdao city. The authors used hydrodynamic module, combined with water quality module, and used these two modules for estimating the environmental capacity of the marine environment with nitrogen and phosphorus nutrients in Jiaozhou Bay. Liao et al [6] based on the study of environmental capacity and environmental quality, calculated three plans of minimizing phosphate in the water in Xiamen Bay, China. Li et al [7] calculated the environmental capacity of heavy metals in Jiaozhou Bay, China. Environmental capacity of heavy metals is the maximum amount of heavy metals allowed in the marine environment to preserve the harmony of the material cycle in the ocean and limit adverse effects on the biosphere and atmosphere, hydrosphere and lithosphere.

The coastline of Vietnam is over 3,260 km length and contains 114 estuaries, annually transporting into the sea about 847 billion m$^3$ of water; 250 million tons of sediment, accompanied by a large amount of nutrients and pollutants [4]. However, according to Dieu et al [4] in Vietnam, assessing the environmental capacity in general and the environmental capacity of water bodies are still relatively novel and have not been paid much attention in researching. In this study, based on the fundamental paper and approach proposed in the [2] and combined with the hydrodynamic and water quality model Mike to assess the environmental capacity for specific object: Dung Quat Bay, in central Vietnam. The results are geared towards helping decision makers look for appropriate management solutions.

2. Materials and methods

2.1. Study area

![Figure 1. Study area location and boundary.](image)

In this research, the geographic location of the area is shown in figure 1. The water level is defined along the open boundary for the flow calculation model. The authors split into two boundaries in figure 1, the second boundary is the East Sea (water level data) and the one containing the discharge
(flow data). Following items will particularly explain the input data model.

2.2. Dataset

2.2.1. Terrain and water level data. Bathymetry data for Dung Quat Bay is taken from General Bathymetric Chart of the Oceans. This is the most reliable, publicly available oceanic data set [8]. Water level data is taken from the MIKE Tide prediction tool, the boundary values are taken along the boundary along the regional terrain are calculated. Meteorological data is extracted from the WRF (Weather Research and Forecasting) model. Tide measurements [9] are used to calibrate and test hydraulic models.

2.2.2. Meteorology. Meteorological data is extracted from the WRF model results - http://www2.mmm.ucar.edu/wrf, data in the form of statistical files should be processed on demand of model. Wind data including wind speed (m/s) and wind direction (degree) are extracted into time series file for inclusion in MIKE model [10].

2.2.3. Monitoring data. The results of the field survey illustrate that the main sources of pollution affecting the coastal water environment is industrial wastewater, which contributes to the coastal ecosystem. In this study, three main waste sources: NT3, NT6 and Tra Bong are considered in figure 2. Quality data of coastal water from monitoring stations from the local environmental monitoring center [11]. The location of NB2, NB3, NB4 monitoring stations is shown in figure 2. The results of seawater quality measurement are the basis for valibration and verification the model of simulating seawater quality, based on that will calculate the environmental capacity for Dung Quat Bay.

2.2.4. Dischargers. According to [11], in the current area, there are many sources of waste discharged into the bay, related data are summarized following: for the discharger NT6: 262 m³/day; for the discharger NT3: 280 m³/day; for the discharger Tra Bong: 200 m³/s. Water quality monitoring data in dry and rainy season, respectively for each discharger is: NT3: TSS are equal to 18 (mg/l) and 10 (mg/l); NH₄⁺ are equal to 0,07 (mg/l) and 0,077 (mg/l)); NT6: TSS are equal to 4 (mg/l) and 3 (mg/l), NH₄⁺ are equal to 0,1 (mg/l) and 0,12 (mg/l); Tra Bong: TSS are equal to 3 (mg/l) and 20 (mg/l), NH₄⁺ are equal to 5 (mg/l) and 5 (mg/l).

2.3. Model

2.3.1. Hydrodynamic module. The hydrodynamic module is based on numerical solution of the depth integrated incompressible flow Reynolds-averaged mass conservation and Navier-Stokes momentum
equations [10]. The governing equations include:

Mass conservation:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0
\]

Momentum conservation:

\[
\frac{\partial \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) + \mathbf{g} = \nabla \cdot \mathbf{T} + \mathbf{f}
\]

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0
\]

\[
\frac{\partial v_x}{\partial t} + \frac{\partial}{\partial y} \left( \rho v_x v_y \right) + g \frac{\partial z}{\partial x} = -\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial}{\partial y} \left( \tau_{xy} \right)
\]

\[
\frac{\partial v_y}{\partial t} + \frac{\partial}{\partial x} \left( \rho v_x v_y \right) + g \frac{\partial z}{\partial y} = -\frac{\partial \tau_{yy}}{\partial y} + \frac{\partial}{\partial x} \left( \tau_{xy} \right)
\]

The following symbols are used in the equations: \( h(x, y, t) \) – water depth (\( = \zeta - d, m \)); \( d(x, y, t) \) – time varying water depth (m); \( \zeta(x, y, t) \) – surface elevation (m); \( p, q(x, y, t) \) – flux densities in \( x \) and \( y \)-direction (m/s); \( \rho_\text{w} \) – density of water (kg/m\(^3\)); \( C \) – concentration (mg/l); \( \tau_{xx}, \tau_{yy} \) – components of effective shear stress.

2.3.2. Advection – diffusion, Ecolab modules. The module is mostly used for modelling water quality as part of an Environmental Impact Assessment (EIA) of different human activities of estuary, creek and open ocean area with MIKE21, MIKE3 hydrodynamics [10]. This research uses the 2D depth-averaged transport equation for a non-conservative pollutant that is given as:

\[
\frac{\partial C}{\partial t} + U \frac{\partial C}{\partial x} + V \frac{\partial C}{\partial y} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} + S + P_c
\]

where \( D_x, D_y \) are the dispersion coefficients in \( x \) and \( y \) direction; \( U, V \) the depth mean velocities in \( x \) and \( y \) directions, respectively (m/sec); \( S \) – source and sink; \( P_c \) – biochemical reactions.

2.3.3. Environmental capacity model. Figure 3 expresses the steps taken in the environmental capacity assessment model implemented in this study. Based on dataset of bathymetry, meteorology and hydrology, it is necessary to calibrate and verify the Mike21 HD, Ecolab model. Note that, during the calibration and verification process, a real data set was used [9]. After the calibration, verification hydrodynamics model and the validated model will be performed to calibrate and verify the Ecolab model for TSS and \( \text{NH}_4^+ \) parameters. After that, the next step is to simulate the water quality of the study area according to two scenarios for dry and rainy seasons, both for two cases of low tide and high tide peaks. These calculation steps use data on waste sources from the results of the local environmental monitoring agency. In order to calculate the capacity of the marine environmental capacity, this study proposed model [2] is used:

\[
EC_{\text{Max}}=(Cs-Cc)\times V/\tau
\]

where: \( EC_{\text{Max}} \) is the maximum environmental capacity of the water body (kg/day); \( C_S \) - concentration limit allowed in standards and standards (mg/l); \( C_c \) - average concentration of substances in the water body (mg/l); \( \tau \) - retention time of water in water body (date); \( V \) - is the average volume of the water body (m\(^3\)) (see figure 3).
3. Result and discussion

3.1. Hydrodynamics calibration and verification

The model is calibrated and verified based on actual water level data measured at coordinates (Long: 108044'E, Lat: 15024'N), Dung Quat main port location in 2017 [9]. Water level boundary data in the form time series is taken from global data, from July 1, 2017 to July 31, 2017 is used for calibration, and for verification to be taken from August 1, 2017 to August 31 2017. Calibration and verification results show a similarity to the permitted level.

3.2. Ecolab calibration and verification

In order to assess the environmental capacity of Dung Quat Bay, in this study, the water quality simulation model Mike21 is used. According to [10], natural nitrification includes a number of different reaction stages and is influenced by parameters related to biochemical processes in the water environment. This leads to the requirement to correct the coefficients related to Ecolab [10]. The results of marine water quality measurement on May 15, 2017 is used for calibrating and the data measured on October 16, 2017 for verifying. The real data were measured by the local Environmental Monitoring Center [11]. The results of calibration and verification are: nitrification: ammonia decay rate at 20 deg is equal to 1 (1/day); Nitrification: Temperature coefficient for nitrification is equal to 1 (dimensionless); Density of dry sediment is equal to 320 (Kg/m$^3$ bulk); Porosity of sediment is equal to 0.25 (m$^3$H$_2$O/m$^3$ bulk); Settling velocity of SS is equal to 0.5 (m/day).

3.3. Environmental capacity

The steps for calculating the environmental load are shown in figure 3. The model MIKE21 has calculated the concentration of NH$_4^+$ and TSS in the study area for two typical seasons: dry season in
May and the rainy season in October. Additionally, this study selects two extreme times for low tide and high tide.

3.3.1. Dry. Calculation results show that at the time of water receding during the dry season, the concentration of $\text{NH}_4^+$ exceeds the allowed concentration in standard for coastal seawater in the aquaculture column ($\text{EC}_{\text{max}} < 0$) [12]. For the column for water sports ($\text{C}_{\text{TC}} = 0.5 \text{ mg/l}$), environmental capacity is still 0.095 (ton / day). For the TSS, the current concentration in the study area is much smaller than the standard, indicating that the area is not contaminated by total suspended solids. The environmental capacity of the bay for TSS target is 7,039 (tons / day). From the results in the dry season and water come up, with $\text{NH}_4^+$, $\text{EC}_{\text{max}} < 0$, according to the coastal water quality column for aquaculture [12], compared to the water column for bathing, water sports ($\text{C}_{\text{TC}} = 0.5 \text{ mg/l}$) still has an environmental capacity of 7,435 (tons / day). However, to ensure a safe environment can only receive 2,231 tons of $\text{NH}_4^+$ per day, this load exceeds the time at the low tide more than 70 times. For TSS, the environmental capacity of the bay is 373 (tons / day), ensuring the safety of the environment is greater than 50 times the time at the low tide at the same month.

3.3.2. Rainy. For the rainy season, for the low tide the bay has been polluted by $\text{NH}_4^+$. According to the calculation, $\text{EC}_{\text{max}} < 0$, the average concentration at this time is greater than the standard for coastal water in aquaculture and exceeding six times compared to the standard for bathing, water sports. This means the environmental capacity of $\text{NH}_4^+$ is 0. For TSS, the capacity environmental of the Dung Quat Bay to ensure environmental safety is 167 (tons / day) greater than the time at the low tidal of dry season more than 20 times. In the rainy season and tide up, the bay has been polluted by $\text{NH}_4^+$. This parameter has a concentration greater than the standard used for coastal water in aquaculture five times and exceeds the standard for bathing, water sports, although not much. That is the reception environmental capacity of $\text{NH}_4^+$ is 0. For TSS, the environmental capacity of the bay is 660 (tons / day) and greater than the tide peaks in dry season are 1.5 times.

4. Conclusion
This study assessed environmental capacity in the Dung Quat Bay, Quang Ngai. Based on the GESAMP methodology for ecological capacity in combination with the hydrodynamic model and the model of water quality, the ecological capacity for dry and rainy periods has been evaluated. The results of the calculations show that the environmental capacity in the bay is better in dry season than in rainy season, in the tide regime, the environmental capacity is better at the high tide than low tide. For $\text{NH}_4^+$, compared to the beach area and water sports standards, the environmental capacity in the dry season is still available, in the rainy season the capacity is not sufficient. If coastal water standards are used for aquaculture purposes, water conservation with $\text{NH}_4^+$, the bay cannot bear the load longer, measures must be taken to minimize the ingress of pollutants. As for the TSS, the environmental capacity is quite high, about 150 tons / day during the dry season and about 400 tons / day during the rainy season.

Appendix
Simulation of pollutants NH$_4^+$ at high tide in May 2017

Simulation of pollutants TSS at high tide in May 2017

Simulation of pollutants NH$_4^+$ at high tide in October 2017

Simulation of pollutants TSS at high tide in October 2017

**Figure A.** Results simulation for NH$_4^+$ and TSS.

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