

Simulation of impact of organic and nutrient pollutants from Nghi Son economic zone on Thanh Hoa coastal waters, North Centre Vietnam

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Received: 26 May 2020; Accepted: 28 December 2020

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Abstract

Nghi Son is an economic zone oriented to developing heavy industry and petrochemicals and has potential to become the most substantial economic zone in the North Central region. The zone is also one of the potential waste sources polluting Thanh Hoa coastal waters. Numeric modeling using Delft3D software package with different scenarios: Current status scenario, controlled discharge scenario, and incident scenario was developed to simulate states of some pollutants of organics and nutrients from the zone to Thanh Hoa coastal waters in different periods. The simulation results show that under controlled discharge (increasing pollutant concentration with the control of waste discharge), the concentration of pollutants was increasing and high around discharging points. In contrast, in incident case from the zone, pollutant concentrations increase markedly both in the magnitude and in the impact range to surrounding areas. When an accident happens, the influence scale will be expanded significantly, especially in the rainy season.

Keywords: Delft3D, water quality, Nghi Son industrial zone, Thanh Hoa coastal area.

INTRODUCTION

Coastal industrial zones planned by the Vietnam Government as core centers for national and regional economic growth, particularly in Central Vietnam, have contributed more and more to socio-economic development in the coastal zone. In contrast, however, these zones have caused high pressures on coastal and marine resources and environments. A clear example is the environmental incident related to the Formosa Industries Corporation, which has caused the coastal environmental disaster in four provinces of the North Central Vietnam. It takes many years to overcome these environmental consequences. This state suggests an improvement of environmental planning and management of the zones with modern tools of numeric modeling that can support assessment of current states and prediction of environmental risks from coastal industrial zones.

Modeling is nowadays often employed to simulate the spread, dispersion of the pollutants, and to forecast the environmental impacts under human activities. The water quality model integration of interactive processes and influencing factors has been applied widely thanks to rapid development of science and technology. To realize the modeling application, the US Environmental Protection Agency (USEPA) has issued guidance criteria on using the model tools for water environment management, including several specific provisions on model/parameter selection for the water quality model [1]. Moreover, the agency has developed an integrated analysis system based on the water quality model to assess the impact of discharge points on water environment [2]. The UK Environmental Protection Agency (UKEPA) recommended using 54 models for surface water quality assessment, including detailed instructions for using these models on a specific case [2]. In China, the Delft3D model system has been used to manage and monitor the water environment in Hong Kong since the 70s of the last century, becoming their “standard” model. In Vietnam, numeric models have been applied to simulate water quality in some bays and the coastal areas. For example,

the Mike and Delft3D models have been used to simulate the spread of pollutants in some coastal areas such as Dinh Vu, Do Son - Hai Phong, Dong Nai - Saigon river basin [3–5], Ha Long - Cat Ba waters, Bai Tu Long bay, Hai Phong coastal waters, Thi Nai lagoon, and Tam Giang - Cau Hai lagoon [6–8].

Nghi Son Economic Zone (NSEZ) is designed in Thanh Hoa coastal area and realized with many different investment projects such as Nghi Son Petrochemical Complex, Nghi Son Thermal Power, Nghi Son Cement Plant, Cong Thanh Cement Plant, Nghi Son Deep-water Port,... These projects generate wastes, potentially polluting the environment in coastal areas of Thanh Hoa in particular and North Central region in general. To contribute to better environment management of NSEZ, numeric modeling of organic and nutrient pollutants from NSEZ with Delft3D software package was simulated and the potential impacts of NSEZ on coastal waters in Thanh Hoa were figured out.

DATA AND METHOD

Data

Digitized coastal bathymetry in the study area was from topography maps of 1:50,000 and 1:25,000 by the Vietnamese People’s Navy (2017) and offshore bathymetry was from the GEBCO-1/8 database (General Bathymetric Chart of the Ocean of British Oceanographic Data Centre) [9, 10]. Sea level data at Hon Ngu station were used for model calibration and validation. The harmonic constants at sea boundaries were extracted from FES2014 of LEGOS (Laboratoire d’Etudes en Géophysique et Océanographie Spatiales, Toulouse) and CLS (Collecte Localisation Satellites) [11]. The meteorological data such as wind, atmospheric pressure, air temperature, solar radiation, and cloud volume from 2017 to 2019 were from NCEP [12]. In addition, salinity and water temperature for the sea boundaries were extracted from the WOA13 database [13] for the Vietnam East Sea.

Besides, measured data were supplemented (current, the concentration of organics and nutrients) from the project “Research on the application of the high resolution satellite

images to monitoring environmental variation in the coastal zones of the North Central Vietnam, VT-UD-02/17–20” to establish and validate the model.

Setting up model

In this study, the Delft3D model system that integrated hydrodynamics - sediment transportation and geochemical processes was used to simulate hydrodynamics - water quality [14]. The model of hydrodynamics and coastal water quality of Nghi Son with orthogonal curvilinear grid type framed all Thanh Hoa coastal zone to southern Ha Tinh province (about 188 km in the northwest-southeast and 150 km in the northeast-southwest direction). The horizontal grid was divided into 197×263 points with the grid cell size between 145.2 m and 1,859.3 m. Along the vertical grid, there were sigma coordinates with five layers (20% of the depth for each layer).

The initial condition: Taking the advantages of Delft3D software, the initial condition of the present scenario employed model calculated results in one-month previous run. Sea boundary conditions were extracted from the Tonkin model (NESTHD method) (figure 1). River boundaries took seasonal average values of discharge, salinity and the main river temperature, such as Ca, Ma rivers. Transport boundary conditions like salinity and water temperature for the model were obtained from the WOA13 database with a resolution of 0.25 degrees for the East Sea [13].

Meteorological condition: The effects of surface wind stress and the temperature exchange across the water surface boundary, wind field, air temperature, sky clouds, solar radiation, atmospheric pressure (3 h, 2.5 deg., NCEP) were used in simulation scenarios.

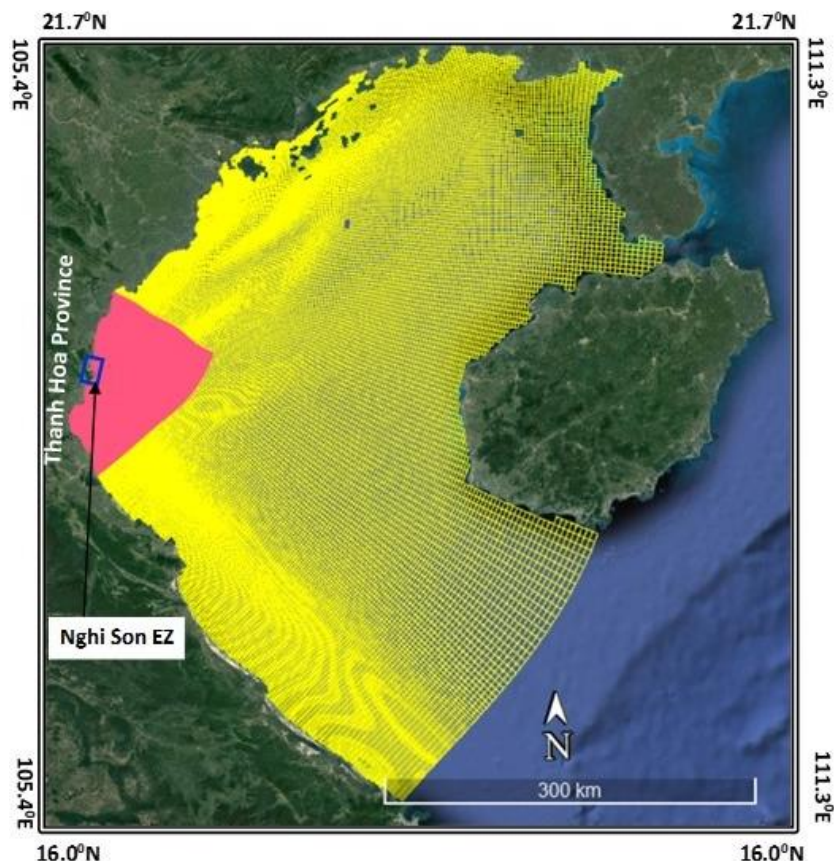


Figure 1. The model grid for Nghi Son coastal area (pink color) and Tonkin Gulf grid (yellow color)

The basic hydrodynamic model processes included salinity, temperature processes, and the influence of surface wind [14].

Establishing water quality model: 3-dimensional (3D) water quality model established at three depth layers (surface, middle and bottom) inherited the hydrodynamic modeling results including grid, water level oscillation, flow, temperature, salinity and other relevant factors [14].

The main computed parameter groups consist of dissolved organic matter (BOD, COD); dissolved nutrients of nitrogen (NH₄,

NO₃), and phosphorus (PO₄). Computation and projection of waste loads from NSEZ are made in two cases of presence and controlled discharge. Therefore, simulated scenarios focus on assessment of contaminant spread and distribution based on waste loads from NSEZ to the coastal area in Southwest monsoon (July - August) and Northeast monsoon (November - December) as follows:

Current status scenario (sc1): Input conditions are present data of organics (BOD, COD), dissolved nutrients (NH₄, NO₃, PO₄) (table 1).

Table 1. Pollution load (ton/year) from NSEZ with different scenario simulations [Source: Project VT-UD-02/17-20]

Water quality parameters	Scenario simulations	
	Present (sc1)	Controlled discharge prediction (sc2)
COD	20,318.2	26,218.5
BOD	4,551.5	7,083.5
NH ₄	2,882.7	6,566.7
NO ₃	134.8	288.3
PO ₄	250.1	432.5

Forecast scenario groups are set up with the modeling parameters as the present scenario (time, water quality model coefficient,...). In simulation scenario (sc2) with controlled discharge points, the concentration of pollutants increases compared to present scenario (table 1), among them: COD (increases by 1.3 times); BOD (1.6 times); NH₄ (2.3 times); NO₃ (2.1 times); and PO₄ (1.7 times). Besides, establishing an incident scenario group is on assumption that wastewater treatment system of NSEZ stops working (wastewater is not treated).

RESULTS AND DISCUSSION

Model validation and calibration

To validate and calibrate model, the Nash-Sutcliffe efficiency coefficient (E) was employed [22] for modeling water level and nutrients (NO₃⁻ and NH₄⁺). The E for water level in Hon Ngu station shows a match both in phase and amplitude between monitoring data and calculations (figures 2a, 2b), ranging from 0.85 to 0.93. The E values calculated between the observed and calculated concentrations of NO₃⁻ and NH₄⁺ from the

model in the dry and rainy seasons are from 0.69 to 0.78 and 0.68 to 0.71, respectively, showing a match between the observation and the calculation (figures 2c, 2d).

Current status simulation

Generally, distribution of pollutant concentrations in the study area changes with tide and season. During the flood tide and high tide, the borders of high contaminated waters are close to shoreline due to the intrusion of seawaters and expanded seaward in the ebb tide and low tide. Thanks to this feature, Thanh Hoa coastal waters are not locally polluted. Seasonally, in the dry season with small river water discharge, the waters with high pollutant concentrations are near the inlets and the discharging locations from the NSEZ, and narrower in area than those in the rainy season.

In terms of the organics, concentrations of BOD and COD vary between 2.5 gO₂/m³ and 4 gO₂/m³ during the rainy season, but are quite small (0.5–2 gO₂/m³) in the dry season. Higher concentrations are in nearshore waters that received waste discharged from coastal and hinterland human activities. Meanwhile, in

offshore areas, the concentrations are significantly lower, mostly less than $1.0 \text{ gO}_2/\text{m}^3$. During flood tide and high tide, waters with small concentrations of organics ($0.5\text{--}1.0 \text{ gO}_2/\text{m}^3$) are narrow and extend

northward, approaching Hon Me island area. In contrast, pollutant sources with organic concentrations less than $1.0 \text{ gO}_2/\text{m}^3$ spread further offshore southeastward during ebb and low tide (figures 3a, 3d, 4a, 4d).

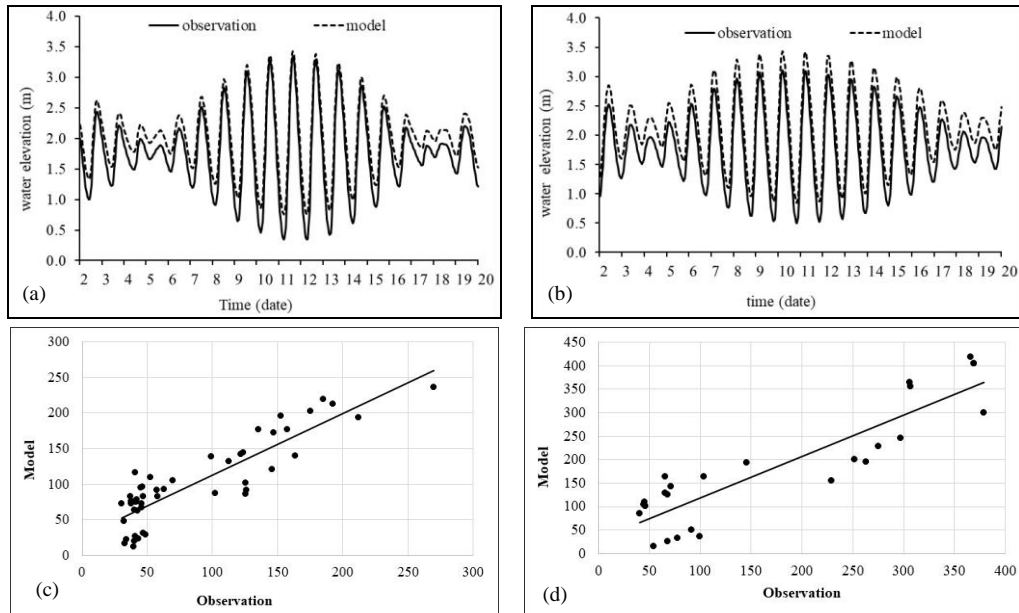


Figure 2. Comparative results of modeling and monitoring water level at Hon Ngu station (a- 8/2018, b- 2/2018); Correlation between observed value and calculation of NO_3 (c- 8/2018; d- 12/2018)

The concentrations of nutrients fluctuate widely from $0.02 \text{ gN}/\text{m}^3$ to $0.012 \text{ gN}/\text{m}^3$. The high levels of NH_4 and NO_3 ($0.06 \text{ gN}/\text{m}^3$ and $0.12 \text{ gN}/\text{m}^3$, respectively) are often concentrated in the coastal zone and estuaries. Whereas in offshore waters, they are mostly less than $0.04 \text{ gN}/\text{m}^3$ (NH_4) and $0.09 \text{ gN}/\text{m}^3$ (NO_3). Areas of high nutrient concentrations in the dry season are quite small compared to those in the rainy season. During ebb tide and low tide, these areas expand further offshore, affecting entire southern and southeast NSEZ. In contrast, during flood tide and high tide, seawater intrusion narrows down the area of high nutrient concentrations to coastal area, pushing these water masses further northward (figures 5a, 5d, 6a, 6d). PO_4 concentration varying widely from $0.025\text{--}0.05 \text{ gP}/\text{m}^3$ in the rainy season is high in some areas near NSEZ discharging sites and low in offshore waters (less than $0.03 \text{ gP}/\text{m}^3$). During the ebb tide/low

tide in the surface layer, water masses containing PO_4 ($0.045\text{--}0.05 \text{ gP}/\text{m}^3$) expand southeastward (30 km) and southwestward (7 km). However, during flood tide, they are pushed a little northward. In short, PO_4 from NSEZ in simulation is insignificant to Nghi Son coastal waters (figures 7a, 7d).

Simulation with the increase of controlled waste sources

In this scenario, BOD and COD from NSEZ wastewater to Thanh Hoa coastal area are supposed to increase by 1.3 and 1.6 times, respectively in comparison with those of current status scenario. Consequently, organic concentrations increase significantly by about $0.1\text{--}0.5 \text{ gO}_2/\text{m}^3$ near NSEZ discharging sites and coastal waters, especially in the rainy season (a rise of $0.3\text{--}0.5 \text{ gO}_2/\text{m}^3$). In offshore waters, no difference between the two scenarios is observed (figures 3b, 3e, 4b, 4e).

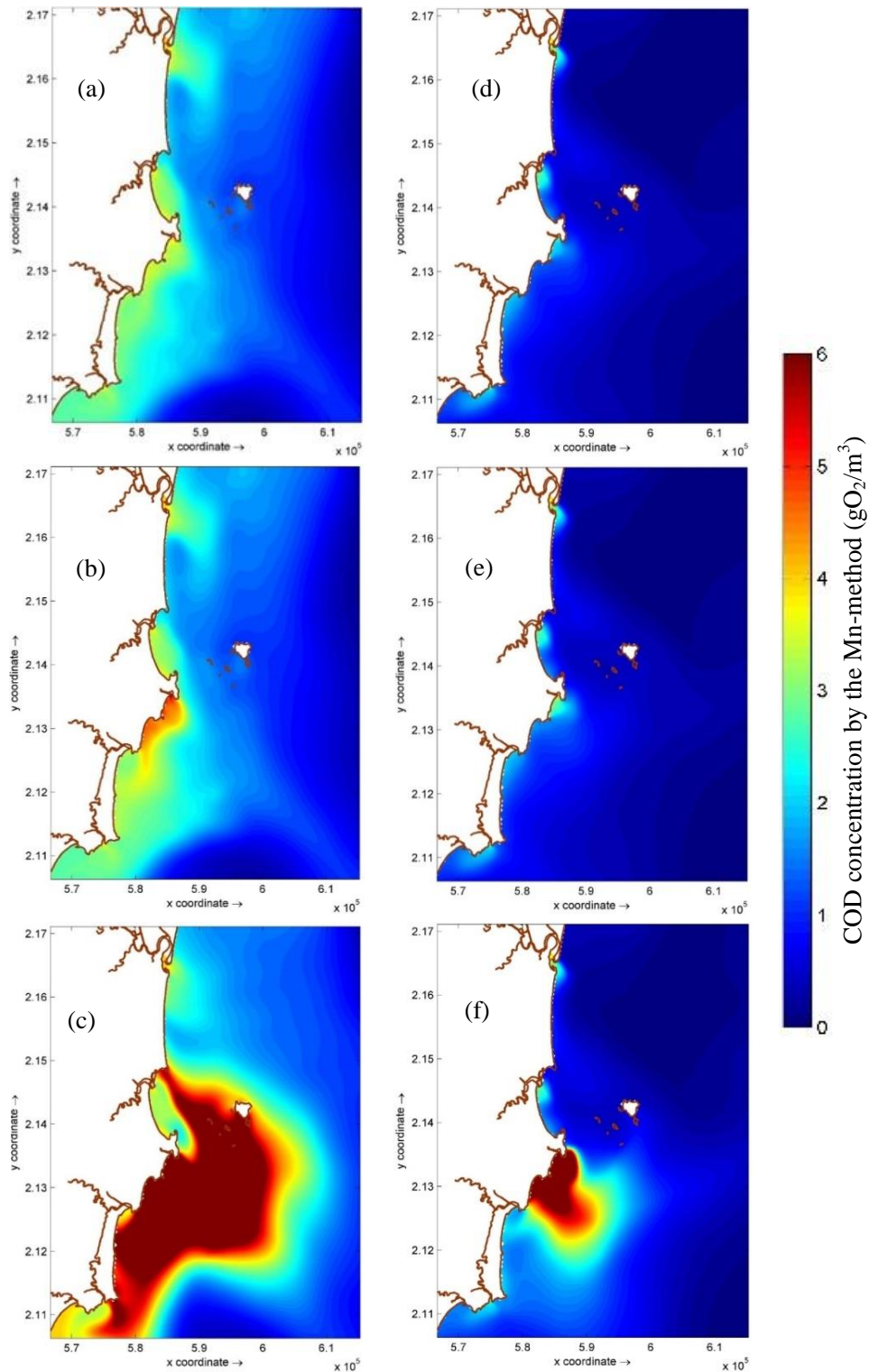


Figure 3. Distribution of COD concentration (gO_2/m^3) in surface layer in Thanh Hoa coastal waters (Rainy season: a- Present, b- Controlled discharge, c- Condition of incident; Dry season: d- Present, e- Controlled discharge, f- Condition of incident)

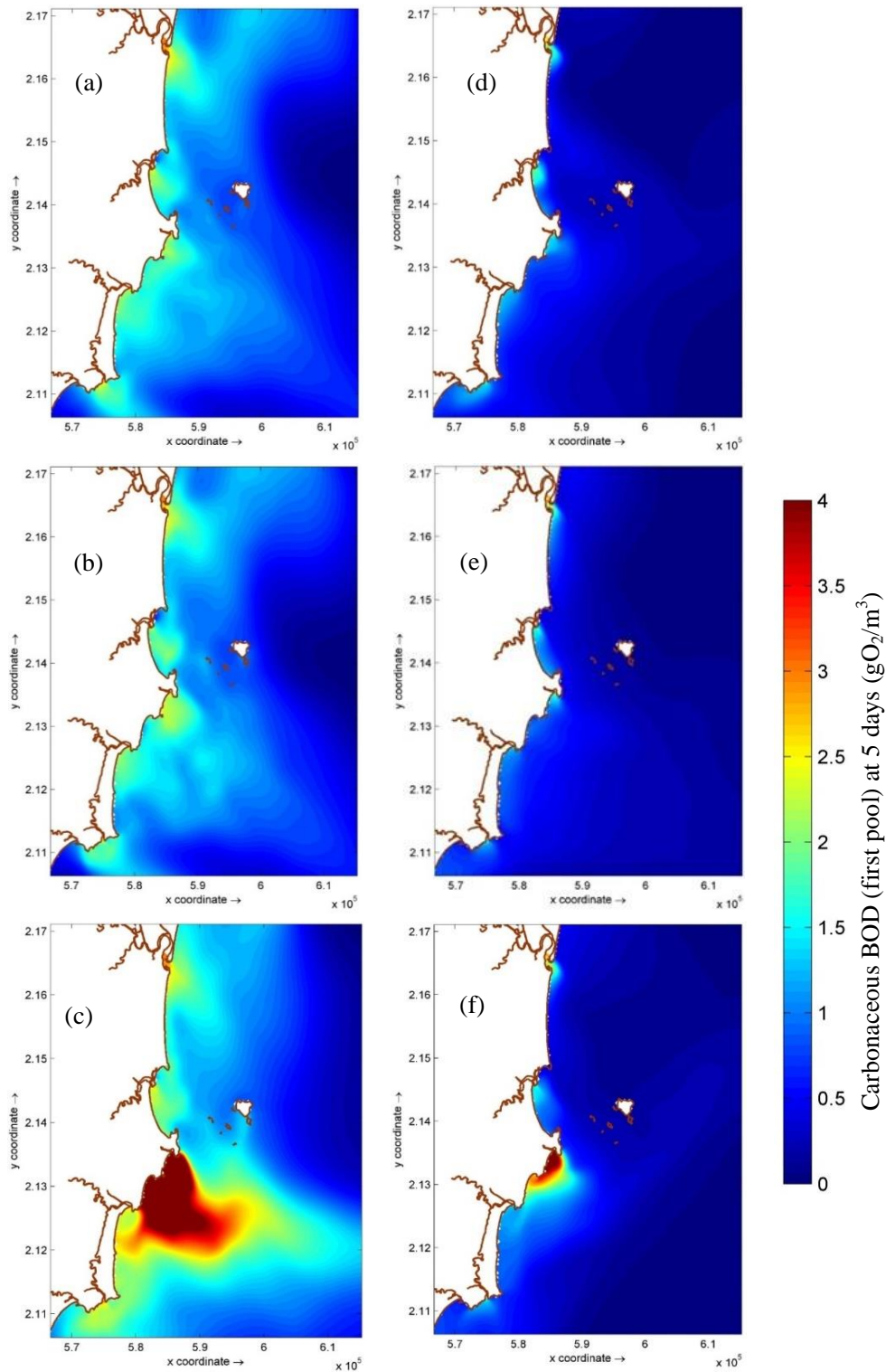


Figure 4. Distribution of BOD concentration (gO_2/m^3) in surface layer in Thanh Hoa coastal waters (Rainy season: a- Present, b- Controlled discharge, c- Condition of incident; Dry season: d- Present, e- Controlled discharge, f- Condition of incident)

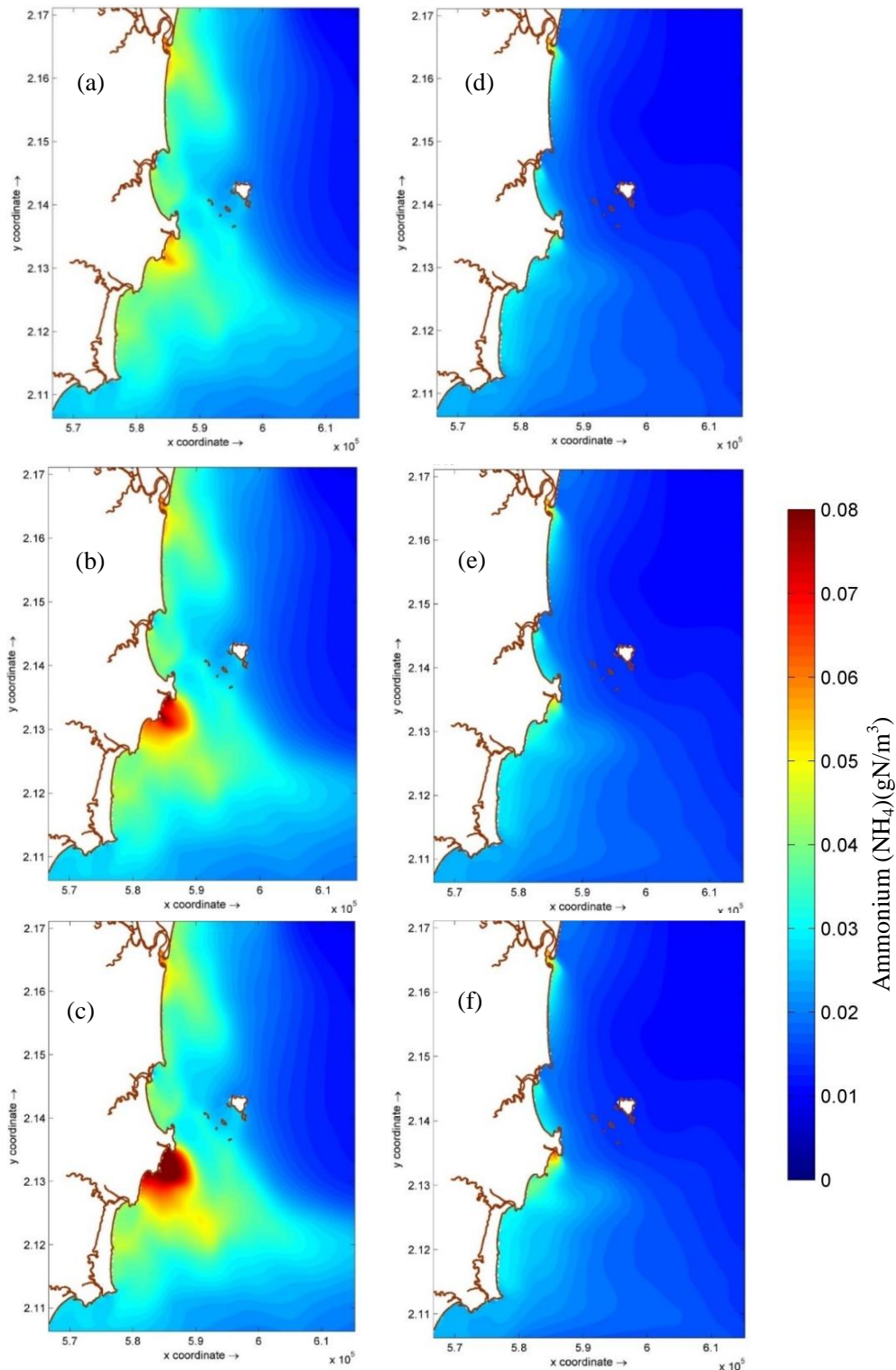


Figure 5. Distribution of NH_4 concentration (gN/m^3) in surface layer in Thanh Hoa coastal waters (Rainy season: a- Present, b- Controlled discharge, c- Condition of incident; Dry season: d- Present, e- Controlled discharge, f- Condition of incident)

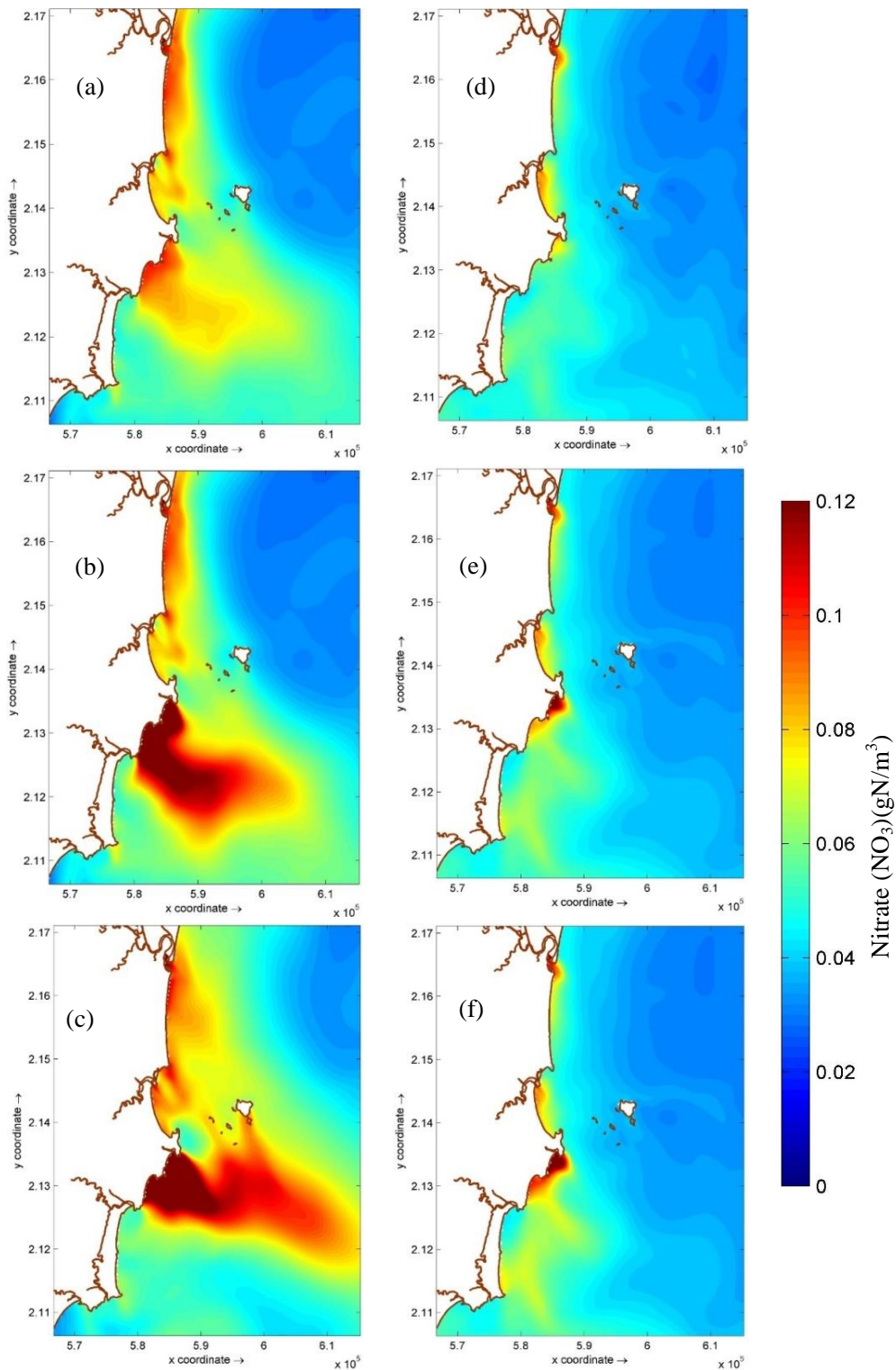


Figure 6. Distribution of NO_3 concentration (gN/m^3) in surface layer in Thanh Hoa coastal waters (Rainy season: a- Present, b- Controlled discharge, c- Condition of incident; Dry season: d- Present, e- Controlled discharge, f- Condition of incident)

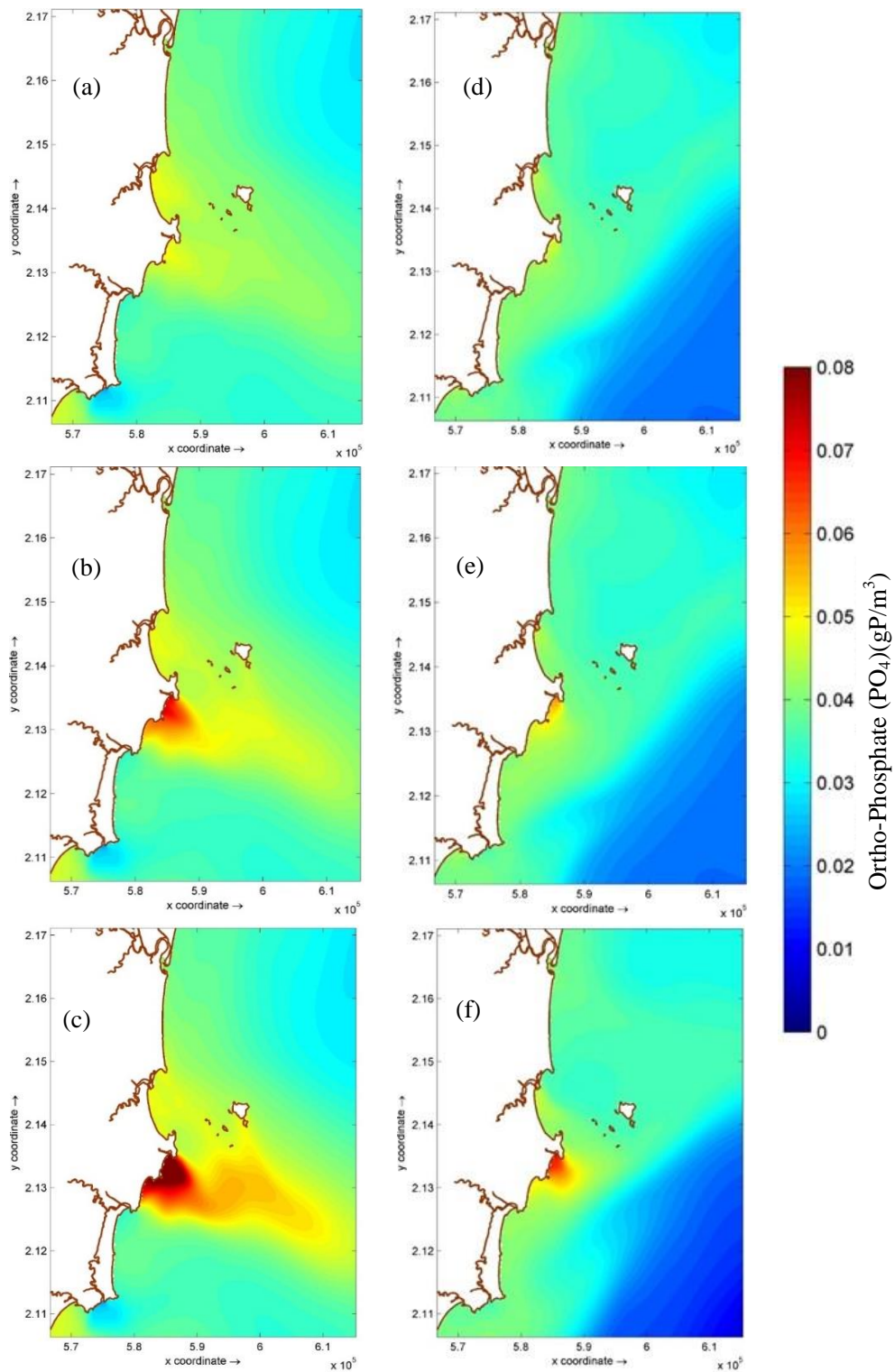


Figure 7. Distribution of PO_4 concentration (gP/m^3) in surface layer in Thanh Hoa coastal waters (Rainy season: a- Present, b- Controlled discharge, c- Condition of incident; Dry season: d- Present, e- Controlled discharge, f- Condition of incident)

Similar to the organics, nutrient concentrations remarkably increase in this scenario. Area of high nutrient concentrations spread out about 20 km seaward (NO_3) during the rainy season, but narrow down mainly near the discharging locations in the dry season. The nutrient concentrations tend to decrease further away from the NSEZ discharging location. It is observed that NH_4 concentration exceeds national technical regulation on marine water quality for aquaculture in the coastal area (QCVN 10-MT:2015/BTNMT), 0.1 gN/m^3 for aquaculture areas and 0.5 gN/m^3 for other regions (figures 5b, 5e, 6b, 6e). PO_4 concentration in the simulated scenario increases in Thanh Hoa coastal areas and expand more outward. In the rainy season, PO_4 concentration increase (0.02 gP/m^3) is mainly in the zone of about 10 km wide from the coast seaward, but only about 0.005 gP/m^3 in the dry season and mostly at the discharging sites (figures 7b, 7e).

Simulation with an environmental accident scenario

Supposing an environmental incident in NSEZ for modeling, a definite state of organic concentration increase is simulatedly observed in comparison with the two other scenarios, both in magnitude and scale. Organic concentrations increase about $1\text{--}2.5 \text{ gO}_2/\text{m}^3$, especially in the areas near discharging sites. The areas of high concentration of the organics expand seaward about 20 km in the rainy season and about 6 km in the dry season (figures 3c, 3f, 4c, 4f).

Similarly, nutrient concentrations increase significantly in comparison with the two other scenarios, are concentrated mainly near the discharging points and spread out about 30 km from the shore in the rainy season (NO_3) (figures 5c, 5f, 6c, 6f). PO_4 concentration from NSEZ to Thanh Hoa coastal waters in modeling also increases significantly in the rainy season and reaches 0.08 gP/m^3 , an increase of 0.04 gP/m^3 compared to the two other scenarios in the area of about 5 km radius from discharging points, and 0.05 gP/m^3 around 25 km seaward. During the dry season, PO_4 concentration increases to 0.02 gP/m^3 , mainly near discharging points (about 5 km from the shore) (figures 7c, 7f).

Discussion

Thanks to its open water, Thanh Hoa coastal waters, part of North Central coastal area in a good regime of water exchange [23] are less polluted because the strong dispersion of pollutants to seawaters, especially in the rainy season with huge water masses from mainland. As a result, the accumulation of pollutants in the sediment will decrease in this season. Contrarily, in the dry season, the accumulation of pollutants in sediment tends to increase, especially near pollution sources. This trend is similar to the tendency of suspended sediment transport in the Red river Delta [15, 16]. In some cases, when extreme weather conditions (waves, strong winds, storm) occur, pollutants from sediment are re-loaded in water, causing local pollution in some coastal waters.

According to national technical regulation on marine water quality of the Ministry of Natural Resources and Environment (QCVN 10-MT:2015/BTNMT) for nutrient concentration (0.1 mg/l for NH_4 ; 0.2 mg/l for PO_4) and QCVN 10:2008/BTNMT for organic concentration (3 mg/l for COD), in the present scenario, the organics and nutrients in Thanh Hoa coastal waters are within allowed limits. In the scenario of the increase of controlled waste sources from NSEZ, the modeling simulation shows that the distribution and concentration of organic and nutrient groups will increase significantly compared to the present scenario, but are still within the allowed limits. In the event of an environmental incident, organic and nutrient pollutants are directly discharged to Thanh Hoa coastal waters without treatment. Although the concentrations of these pollutants increase sharply, the waters with concentrations of nutrients and organics higher than permitted standards appear only near some discharging points. Most others remain below the permissible limits. This confirms the role of dynamic and morphological conditions of open waters in reducing the risk of local pollution in coastal areas [6, 7, 19, 20].

In current status scenario, simulation shows that nutrient and organic concentrations in nearshore area with waste sources from NSEZ are significantly different from those in

offshore area. The influence of waste sources from NSEZ on water quality is considerable in comparison with other sources. It is different from the impact of waste sources from the Dinh Vu industrial zone of Hai Phong [19] and pollution sources from rivers compared to other sources [24–26].

The application of numerical modeling to water quality assessment due to industrial activities has been studied in many coastal estuaries around the world [19, 27, 28]. Phiri et al., [29] announced that the pollution of industrial zone waste play a huge role in the quality of the water environment in the coastal areas, and the pollution of coastal river estuaries in developing countries has been caused by industrial waste sources. Muwanga and Barifaijo [30] through their research results, demonstrated that the industrial waste source is the main factor causing a strong decline in the water environment of Lake Victoria (Uganda). Department of Environment in their Environmental Quality Report 2009 (Malaysia) showed that 46% river water of Malaysia is polluted with higher level than in previous couple of years [31]. The results in this study indicate that sources of pollution have not had a great impact on water quality in Thanh Hoa coastal area. However, the pollution load from the NSEZ tends to increase in the next years. Thus, these influences should be considered for the management of water environment of the Thanh Hoa coastal waters.

CONCLUSION

A hydrodynamics - water quality modeling system of Delft3D software applied for different scenarios on the impact potentials of some pollutants (BOD, COD, NH_4 , PO_4 , NO_3) from NSEZ to Thanh Hoa coastal waters indicates its appropriation to simulate environmental pollution caused by natural and human processes, e.g. in Thanh Hoa coastal waters particularly and North Central coast generally.

Simulated organics (BOD, COD) and nutrients (NH_4 , PO_4 , NO_3) in Thanh Hoa coastal waters in complex processes are affected mainly by factors of discharges from rivers and NSEZ, and tide. Due to good water

exchange making high dilution, for all three scenarios, the waters with organic and nutrient concentrations exceeding the permissible limits are only at small scale and near discharging points. In this study, impact simulation of pollutants from NSEZ on Thanh Hoa coastal waters is made for each of the three scenarios. Combined effect of all the waste sources is not simulated and needs to take into account for the regional water quality.

Acknowledgements: This article received the support of the project “Research on the application of the high resolution satellite images to monitoring environmental variation in the coastal zones of the North Central Vietnam” VT-UD-02/17–20 and the project “Management of the water quality in Vietnamese coastal waters impacted by CLIMate change and human induced DISasters using a marine modelling tool” NĐT.97.BE/20. The authors would like to thank that valuable support.

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