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Impacts of pollution discharges from Dinh Vu industrial zone on water quality in the Hai Phong coastal area

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Abstract
The hydrodynamic and water quality models (the Delft3D model) were established based on the measured data and the estimated pollution discharges from Dinh Vu industrial zones to Nam Trieu estuary. With seven separate simulation scenarios, the results show that in case of increased wastewater with the control of pollution discharge (water and concentration), the impact of pollution is only limited to a small area around the discharge point. Their influences on water quality in other areas in Nam Trieu estuary are quite small. Meanwhile, in case of environmental risk, a strongly increasing pollution load would cause the significantly increasing pollutant concentration in this area, they have almost exceeded the value in the National Technical Regulation on surface water quality (QCVN 10-MT:2015/BTNMT), such as NH_4, COD, and BOD. Dissolved oxygen in the water would also decrease significantly. The spatial influence extends from the discharge point to Nam Trieu estuary, inside Cam, Bach Dang rivers, and Cat Hai coastal area.

Keywords: Delft3D, water quality, Dinh Vu industrial zone, Hai Phong coastal area.

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INTRODUCTION

The pollutant sources that enter the basin are often affected by complex biogeochemical processes. Under the effect of these processes, the exchange of contaminants not only takes place within these processes but is also affected by other processes such as hydrodynamics, transport of water masses,... Therefore, it is very difficult to assess and forecast the ability of spread of contaminants from sources as well as their impact on the water environment of the region. Although traditional measurement and survey methods can provide status information, there are many limitations (equipment, time, surveyors,...). In recent years, by developing the computational tools, the exploitation and use of numerical models become easier and more efficient [1, 2]. The numerical models not only provide information on current conditions but also predict the change of water quality due to the influence of pollutant sources [3, 4]. Because of these advantages, the application of model tools is more and more widespread in the world [3–5]. In Vietnam, in recent years, the model tools have been applied in the studies of the water quality forecast and the assessment of the environmental capacity in Ha Long - Bai Tu Long bay, Thi Nai lagoon (Binh Dinh province), Hai Phong coastal area, Cat Ba - Ha Long area, producing very positive results [6–8].

Dinh Vu industrial zone (DVIZ) is one of the largest industrial zones of Hai Phong city located in the coastal area of Bach Dang-Nam Trieu estuary. This area is affected by the tropical monsoon climate with a contrast between two monsoon seasons: The Northeast monsoon (November-March) and the Southwest monsoon (April-September). Although receiving a large amount of water and sediment from Red river delta, it is unevenly distributed every month, most of which is concentrated in the months during the rainy season [9]. Moreover, this region is dominated by the diurnal tide regime with a high tidal amplitude, leading to a better water exchange than other areas [10]. DVIZ is now one of the most exciting and important industrial zones which contribute to the socio-economic development of the city. The water pollution from DVIZ has been controlled, but its impacts on the water environment of Nam Trieu - Bach Dang estuary as well as Hai Phong coastal area in general are still worrying. Even so far, there are only several individual reviews in the environmental impact assessment reports, there has been no study on the combined influences of the DVIZ on the water quality in this region. Based on the results of setting up the Delft3D model to simulate and forecast water quality of the area, this study will contribute to clarifying the impacts of different waste sources from DVIZ on water quality of the Hai Phong coastal area.

MATERIALS AND METHODS

Materials

To serve the establishment of a numerical modeling system for the coastal estuary area of Hai Phong, data have been collected and processed.

Bathymetry and coastline in the Hai Phong coastal area and Ha Long - Bai Tu Long bay were digitized from topography maps with scales of 1:50,000 and 1:25,000 that were published by the Vietnamese People’s Navy in 2017. Bathymetry of the offshore and neighboring areas as well as the Gulf of Tonkin was gained from the GEBCO-1/8 database (General Bathymetric Chart of the Ocean (GEBCO) of British Oceanographic Data Centre-BODC) [11]; water elevations at Hon Dau station were used to calibrate the model. These data were measured with an interval of 1 hour from 2016 to 2017. The harmonic constants at sea boundaries were extracted from FES2014 of LEGOS (Laboratoire d’Etude en Géophysique et Océanographie Spatiales, Toulouse) and CLS (Collecte Localisation Satellites) [12].

The data of observed waves and wind in 2016–2017 at Hon Dau station were collected and processed as input for the model. These data (every 6 hours) were used for the present scenarios. The river water discharge at some hydrological gauging stations such as Cua Cam, Trung Trang, Quyet Chien, and Nam Dinh in 2016–2017 was also analyzed and assessed based on the establishment of the river boundaries of the hydrodynamic model.

Data (water temperature, salinity, and flow) in the coastal area of Hai Phong and the Gulf of Tonkin were collected from research results during 2016–2018 to establish and validate the model, namely "Study and assessment of pollutants spreading from rivers to the coastal zone of Hai Phong, DT.MT.2008.500", "Research on the basis for the planning of dumping site for dredged sediment disposal in the Hai Phong coastal area, DT.MT.2015.721" and "Research on the impact of sand mining activities on the hydrodynamics, sediment transport and morphological change in Hai Phong coastal area, DT.MT.2017.792". Besides, salinity and water temperature for the sea boundaries were extracted from the WOA13 database [13] for the East Vietnam Sea. This study has also used the results of water quality survey (table 1) and the discharge load from DVIZ (table 2) of the Hai Phong project "Study and assessment of the environmental capacity from DVIZ regarding the ability to receive chemical and petrochemical projects".

Table 1. Comparison between measured data and simulation results

No.	Point	DO (mg/l)		BOD (mg/l)		COD (mg/l)		Suspended sediment (mg/l)		NH_4 (µg/l)		PO_4 (µg/l)	
		O	M	O	M	O	M	O	M	O	M	O	M
1	B1	5.8	5.5	2.6	2.3	4.1	4.0	44.2	49.2	125.9	129.6	54.2	55.5
2	B3	5.1	5.4	3.0	2.5	3.7	3.5	65.1	68.1	151.3	160.7	76.3	60.7
3	B5	6.2	6.2	2.9	2.5	3.8	3.4	43.8	50.2	103.8	105.2	43.2	44.5
4	B6	6.3	6.1	2.9	2.4	4.3	4.0	45.1	51.1	109.7	112.4	72.5	75.5
5	B7	6.4	6.4	3.3	3.1	4.3	3.9	45.8	48.5	119.9	125.5	60.0	61.1
6	B8	6.7	6.3	3.4	3.2	4.2	4.1	42.0	45.2	107.5	108.9	61.0	63.2
7	B9	6.7	6.5	3.0	3.1	4.4	4.2	44.0	45.0	120.1	122.6	81.0	81.9
8	B12	7.1	6.5	2.5	2.5	3.7	3.5	36.7	40.1	128.4	129.4	60.7	62.3
9	B14	7.2	6.7	2.4	2.6	3.7	3.6	35.8	38.9	198.8	180.4	62.3	64.4

Notes: O: observation, M: model.

Methods

The main method used was to set up the hydrodynamic-water quality models based on the Delft3D with different scenarios (present situation and prediction of the increase in water pollution). The results of the analysis and comparison between these scenarios will provide information on present conditions as well as forecast the impacts of the wastes from DVIZ on the water environment in the coastal area of Hai Phong.

Hydrodynamic model for Hai Phong coastal area used orthogonal curvilinear grid type. The model frame included all the coastal zones that covered the north of Ha Long bay to the south of Tra Ly estuary. The region expanded about 106 km in the northeast-southwest and 64 km in the northwest-southeast direction with a water surface area of 5,085 km^2. The horizontal grid of the model was divided into 628 × 488 points with the grid cell size between 8.3 m and 340 m. Along the vertical grid, there was sigma coordinate with 5 layers (20% of the depth for each layer). The bathymetry grid for the model in this area was the terrain data file that was processed and tied to the calculated grid of the model.

The initial condition of the Delft3D model can use a restart file that was the result of the previous run. In this study, the results of a month run for Hai Phong coastal area were used for the initial condition of present scenarios.

There are river and sea boundaries. For river boundary conditions, this study used water discharge, salinity, temperature, the average concentration of seasonal suspended sediment in the main rivers such as Bach Dang, Cam, Lach Tray, Van Uc, Thai Binh, Tra Ly and some small rivers in Ha Long area. For sea boundary conditions, we used the results from an outside coarse model that is the NESTHD method in the Delf3D model. 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 Vietnam Sea.

In this study, the hydrodynamic model was set up for the type of online coupling of processes such as salinity, temperature, suspended sediment transport, the effect of surface wind, and wave-current interaction. In terms of meteorological conditions, this study only considered the influence of wind, other factors such as humidity, precipitation, radiation, and air temperature were not included in the model. The wind data at Hon Dau station from 2016 to 2018 with an interval of 6 hours were used for the meteorological forcing condition of the model.

The water quality model also used the calculated results of the hydrodynamic model, including grid, bathymetry, water level, depth change, flow field, water temperature, and salinity [14]. The water quality model was a 3D model with 3 vertical layers (33% of water depth for each layer). The parameters of the water quality included dissolved oxygen (DO); dissolved organic matter (biochemical oxygen demand-BOD, chemical oxygen demand-COD); dissolved nutrients of nitrogen (ammonium-NH_4, nitrate-NO_3), phosphorus (PO_4), and suspended sediment.

For the calibration, the water quality model was simulated in January 2015 and July 2016. The water quality simulation scenarios were calculated in the rainy season (July-September, 2017) and the dry season (January-March, 2017). The time step for each calculation scenario was 30 seconds.

Simulation scenarios

To assess the impact of water pollution from the DVIZ, the simulation scenarios were established based on water pollution scenarios (table 2). Each simulation scenario was conducted in the rainy and dry seasons.

Table 2. Pollution load (ton/year) from DVIZ with different simulation scenarios

Water quality parameters	Simulation scenarios					
	kb1	kb2	kb3	kb4	kb5	kb6
COD	70.2	642.1	1,337.0	2,444.0	2,639.0	28,484.0
BOD	45.0	475.9	861.7	1,636.7	1,614.2	16,679.9
NH_4	1.7	188.7	1,230.1	3,182.6	1,230.1	3,182.6
Suspended sediment	99.0	63,493.5	63,495.2	80,321.0	64,569.7	91,066.0
PO_4	1.3	97.7	242.3	2,933.1	242.3	2,933.1

These scenario groups were set up with the same modeling parameters as the present scenario, except the water pollution output from the DVIZ to the coastal zone (table 2). Besides, we also establish the 7th scenario (kb7), which has the same conditions as the previous scenarios but it is assumed to have an uncontrollable issue of waste load: All wastewater in the storage tank of the wastewater treatment without processing would be discharged into Nam Trieu - Bach Dang area within 15 days.

RESULT AND DISCUSSION

Model validation and calibration

To evaluate the reliability of the calculations, the Bravais-Pearson correlation coefficient and the Nash-Sutcliffe efficiency coefficient (E) were used [15]. E coefficient allows assessing the number of forecasts ensuring reliability. E varies from 1.0 (perfect match) to $-\infty$, a negative value indicating that the mean value of the observed time series would have been a better prediction than the model [16].

The assessment results indicate that the coefficient of correlation R varied within 0.91–0.95 (for water elevation level) and from 0.79 to 0.82 for the flow velocity. Meanwhile, the E values changed between 0.82–0.86 (for water elevation level) and 0.71–0.75 for flow velocity. Some model results have been compared with the water status measurements at Bach Dang - Nam Trieu (figure 1). The comparison result (table 1) shows a match between the observation and the calculation.

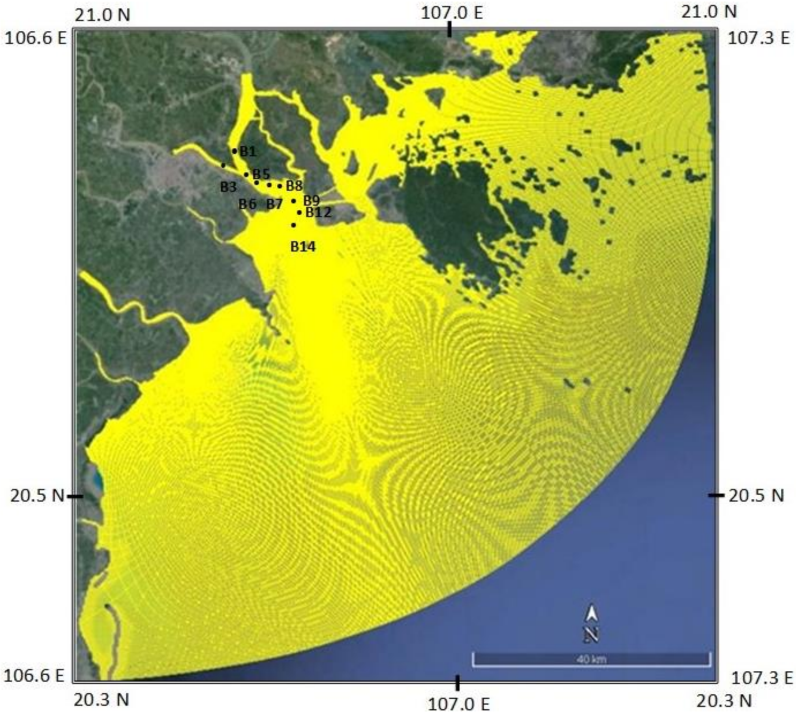

Figure 1. The model grid and position of water quality sampling points

Present situation of water quality in Hai Phong coastal area

COD

The simulation results show that COD in the study area changed over time due to tidal oscillation and season. During the rainy season, the COD concentration in the coastal area of Hai Phong varied between 3 gO_2/m^3 and 5 gO_2/m^3. Some areas (Bach Dang, Cam, Lach Tray) have higher levels of COD because they are near discharge points (figure 2a). Meanwhile, in the offshore area, the COD concentration is smaller, at 1–2 gO_2/m^3 because this area is less affected by socio-economic activities in coastal areas and waste sources from the continent.

The various field currents and tidal oscillation have a significant impact on the spatial distribution of the COD. As a consequence, high levels of COD in water were shrinking in the flood and high tides due to the penetration of seawater into the estuary. Conversely, in the ebb tide as well as low tide, the river water grows sharply to the sea, the waters with higher levels of COD also extend from the outer coastal area (figure 2a). The model results also showed that the impact of the sources of wastewater from the DVIZ on COD concentration distribution in Nam Trieu as well as in the Hai Phong coastal area is relatively small. This source of pollution affects only small areas near the waste source (see figure 2a).

In the dry season, due to the decrease of river discharge, the variation of COD concentration is more closely dependent on the tidal phase. The COD concentration in the coastal estuary of the Hai Phong city mainly varies between 3–6 gO_2/m^3. The area of higher COD value is located inside of river or near the location of the waste source from the continent. Meanwhile, the area with high COD concentration is also narrower, mainly concentrated near the river mouth and the coastline. The trend of distribution and fluctuations in COD concentration in the dry season is the same as in the rainy season. However, as the water flow during the dry season is relatively small compared to the rainy season, the high concentration of COD is focused mainly in the areas within the estuaries and the waters of the coast with a relatively small range.

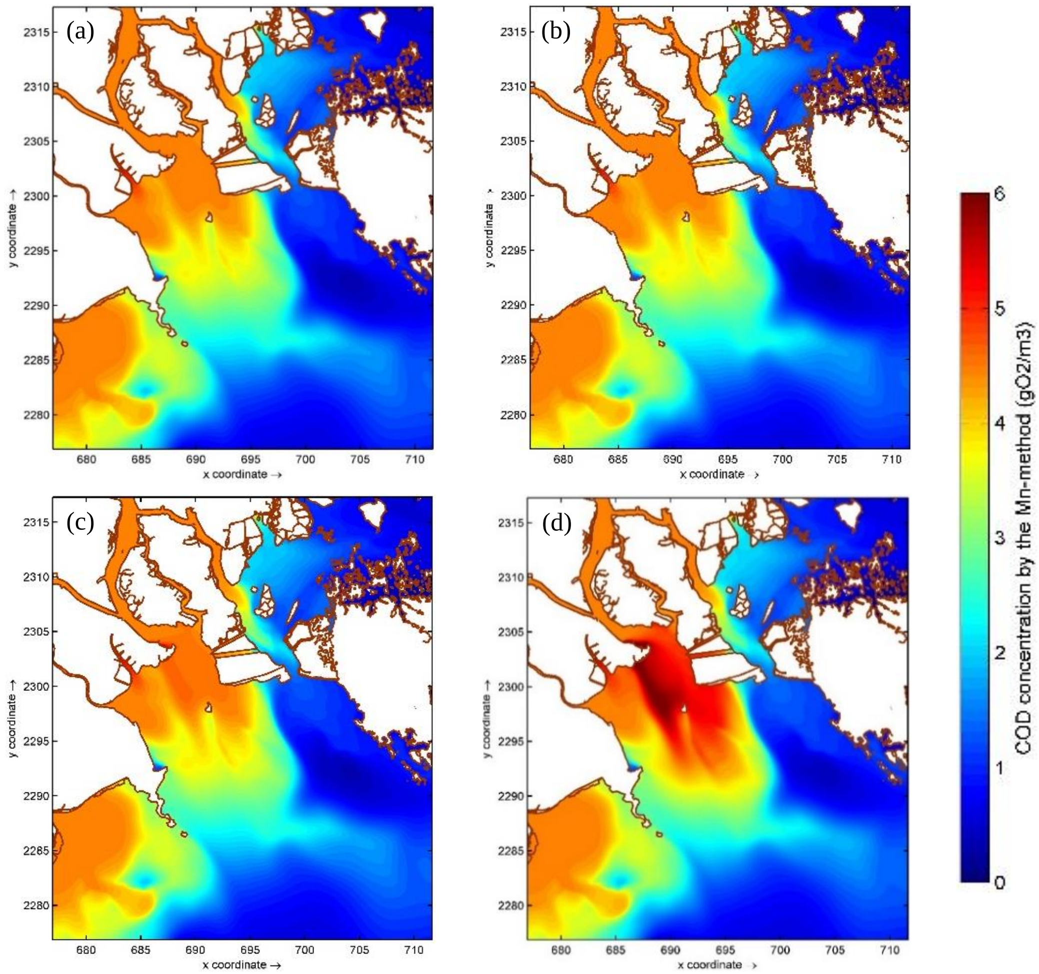

Figure 2. Distribution of COD concentration (gO_2/m^3) on surface layer in Hai Phong coastal area, during ebb tide, in rainy season (a- present, b- kb2, c- kb5, d- kb7)

BOD

The fluctuation trend of BOD is similar to that of COD. During the rainy season, the concentration of BOD in the coastal area of Hai Phong changes within 1.0–4.0 gO_2/m^3. Some areas (Bach Dang river, Cam, Lach Tray, and Van Uc river mouth) have a higher concentration than other places. These regions are near the discharge point as well as water pollution from the continent. Meanwhile, in outlying areas, the concentration of BOD is mostly less than 2.0 gO_2/m^3 (figure 3a).

Because of the influence of tidal oscillation, the spatial distribution of the water masses with high BOD concentration varies mainly according to the time. During flood tide and high tide, the area with a high BOD concentration is narrowed inside the estuaries. In contrast, during ebb tide and low tide, the source of pollutants is extended offshore (figure 4a). This feature makes the ability of pollutant diffusion in the Hai Phong coastal area increase while reducing the possibility of local pollution in this area.

The simulation calculations show that BOD in the research area during the dry season is more evident in tidal phase fluctuations with the distribution of high-concentration waters in the estuaries. The BOD concentration in the dry season commonly fluctuates between 2.0–4.0 gO_2/m^3. The places close to the discharge point (Bach Dang river, Cam, Lach Tray, and Van Uc mouth) have a higher value of BOD concentration than the others. Meanwhile, in offshore areas and the south of Cat Hai, the southwest of Cat Ba, and other areas, the BOD concentration is mostly less than 1.5 gO_2/m^3.

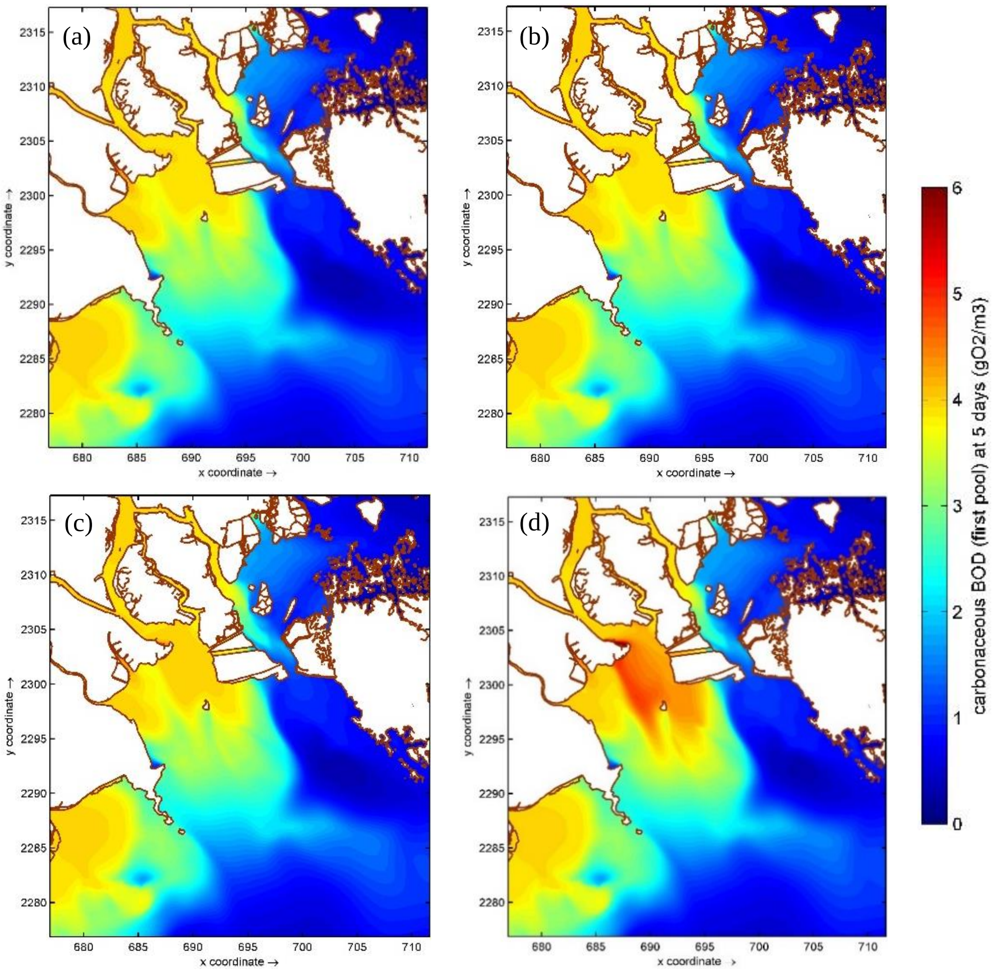

Figure 3. Distribution of BOD concentration (gO_2/m^3) on surface layer in Hai Phong coastal area, during ebb tide, in rainy season (a- present, b- kb2, c- kb5, d- kb7)

NH_4

In the rainy season, the NH_4 concentration in Hai Phong coastal area varies widely from 0.06 to 0.15 gN/m^3 and shows the main influence due to tidal fluctuations, the interaction among river masses, and seawater. Some areas with higher NH_4 concentration are the water regions such as Bach Dang, Cam, Lach Tray, and Van Uc rivers that receive water and nutrients from the continent; whereas in the offshore area, NH_4 concentration is mostly less than 0.05 gN/m^3.

Due to the strong tidal fluctuations, the distribution of water region with a high NH_4 concentration also varies significantly. During times of ebb tide or low tide, the river-coastal waters can expand offshore as well as waters with high NH_4 values (figure 4a). In contrast, during flood tide and high tide, the intrusion of seawater makes the water areas with a high NH_4 concentration narrowed to the coastal area. This feature causes the increase in the ability of pollutant diffusion in the coastal area while reducing the possibility of local pollution. The simulation results show that NH_4 value from DVIZ in the present situation does not have much impact on spatial distribution and tidal fluctuations of NH_4 in the coastal area of Hai Phong.

In the dry season, NH_4 concentration in Hai Phong coastal area varies between 0.02 gN/m^3 and 0.15 gN/m^3. Some river mouths such as Bach Dang, Cam, Lach Tray, Van Uc have higher NH_4 concentration than other areas, receiving waters as well as nutrients from the continent. Meanwhile, in offshore areas and the southwest of Cat Hai - Cat Ba coastal area, the NH_4 value is mostly less than 0.3 gN/m^3. The area with high NH_4 content in the dry season is smaller than that in the rainy season. The distribution of waters with a high NH_4 concentration also varies rapidly with the tidal fluctuations. During the ebb tide or low tide, the river-coastal waters can expand offshore as well as waters with high NH_4 concentration. In contrast, during the flood tide and high tide, the intrusion of seawater makes the high NH_4 area narrowed to the coastal area.

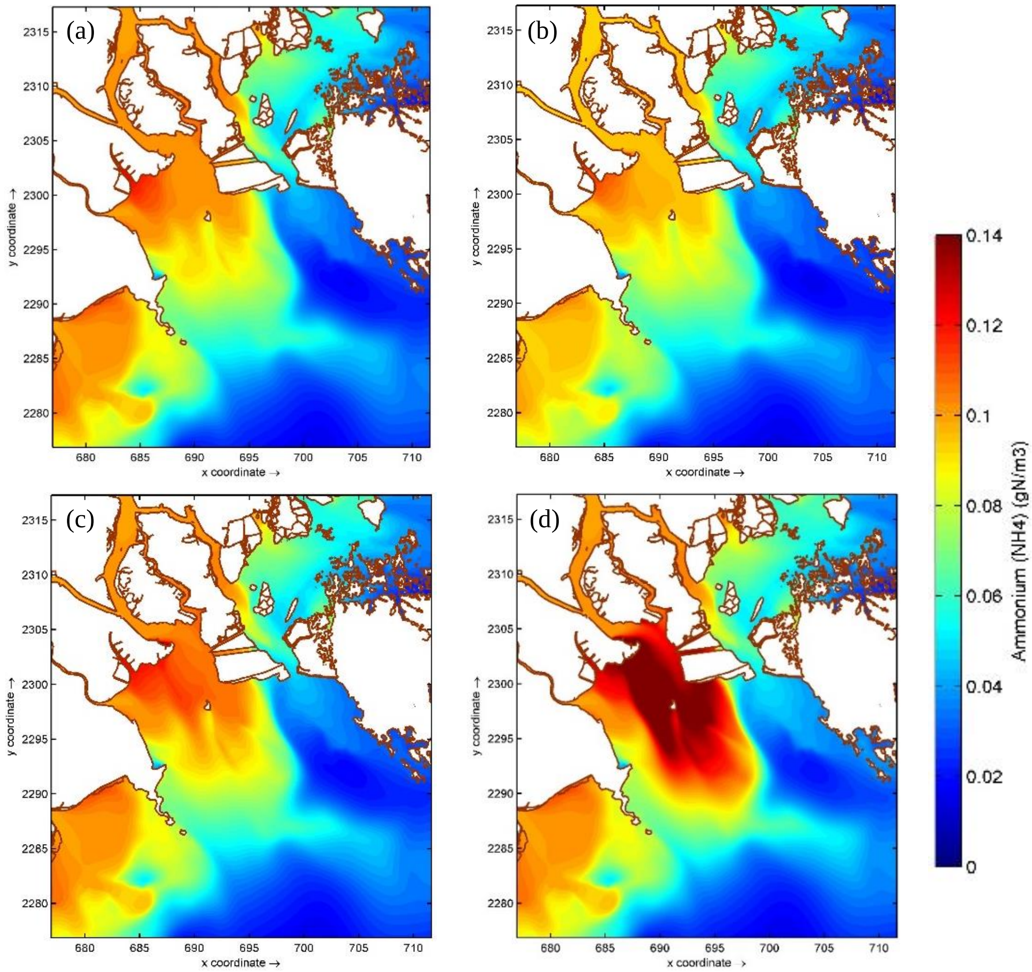

Figure 4. Distribution of NH_4 concentration (gN/m^3) on surface layer in Hai Phong coastal area, during ebb tide, in rainy season (a- present, b- kb2, c- kb5, d- kb7)

PO₄

The simulation results of spatial distribution and time fluctuation of PO_4 in the study area show that they are mainly influenced by water level fluctuation, the interaction between freshwaters and seawaters.

In the rainy season, PO_4 concentration in the coastal area of Hai Phong - Quang Ninh changes from 0.02 gP/m^3 to 0.07 gP/m^3, and is higher in some estuaries such as Bach Dang, Cam, Lach Tray and Van Uc rivers that receive water and nutrients from the continent.

Meanwhile, in the offshore area and Cat Ba - Cat Hai coastal area, NH_4 concentration is mostly less than 0.03 gP/m^3.

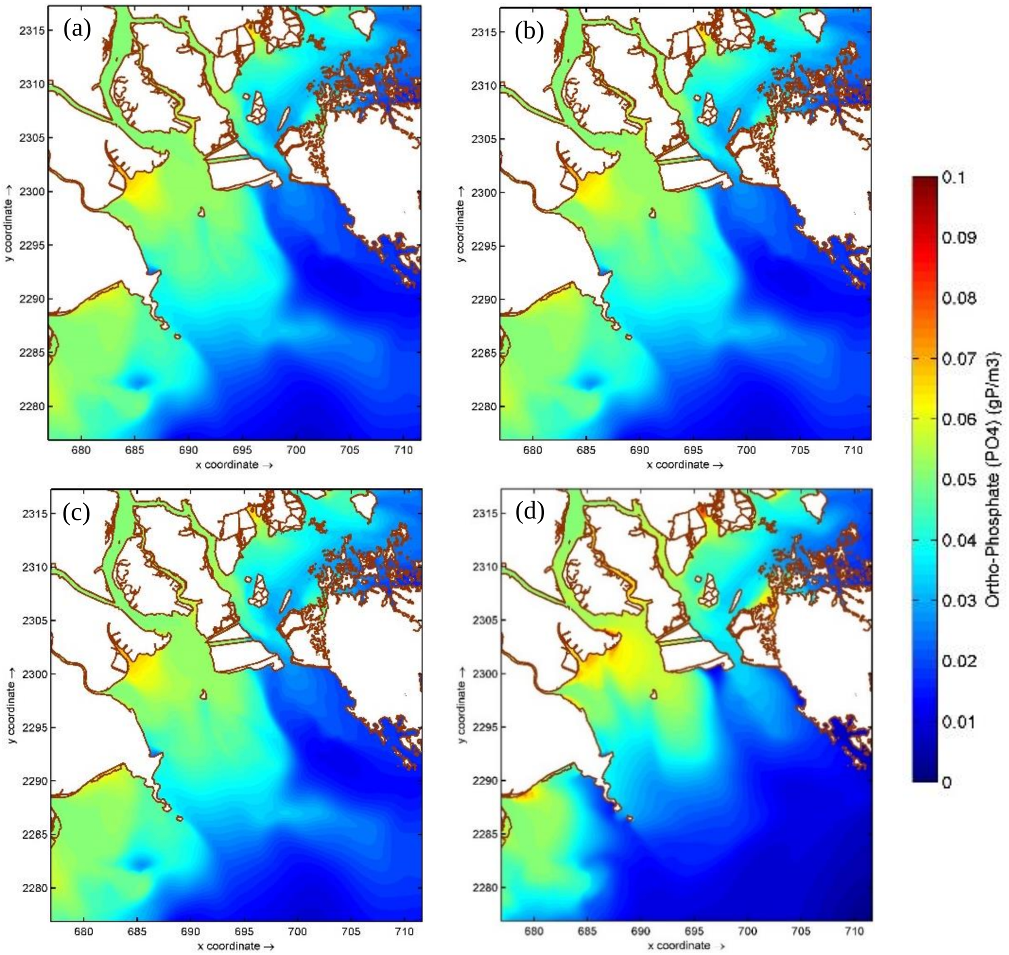

Figure 5. Distribution of PO_4 concentration (gP/m^3) on surface layer in Hai Phong coastal area, during ebb tide, in rainy season (a- present, b- kb2, c- kb5, d- kb7)

In the dry season, the PO_4 concentration varies widely from 0.03 to 0.06 gP/m^3, but the range of areas with high PO_4 value has been narrowed and significantly reduced compared to that in the rainy season. Areas with higher levels of PO_4 are still inside the river mouth (Bach Dang, Cam, Lach Tray, and Van Uc), which received a great source of water and nutrients from the continent. Whereas in the offshore are and the southwest of the Cat Ba - Cat Hai area, the PO_4 concentration is mostly less than 0.02 gP/m^3.

The area with the high PO_4 value varies strongly with the tidal fluctuation. During ebb tide or low tide, the river waters conditionally extend far from the shore, thus the waters with high PO_4 concentration develop more strongly offshore (figure 5a). In contrast, during flood tide or high tide, the intrusion of seawater makes the high PO_4 areas narrowed to the nearshore area. The diffusion - transport of material at the discharge points to the offshore area always takes place, contributing to increasing dilution with seawater and reducing the possibility of local pollution for this area.

Suspended sediment

Suspended sediment does not cause serious effects on the organism but on the processes of photosynthesis in the aquarium. The modeling results showed that during the rainy season, the suspended sediment concentration (SSC) in the coastal area of Hai Phong changed within 50–130 mg/l. Similar to other water quality parameters, higher SSC appeared in river mouths such as Bach Dang, Cam, Lach Tray, Van Uc, and near the coastal area. Other regions have a smaller SSC value. The spatial and temporal variations of SSC show the influence of the tide. In the ebb tide and low tide, higher SSC regions develop and expand seawards. During flood tide and high tide, the areas with high SSC value push close to the river mouth. In the dry season, although the suspended sediment fluxes from the river decrease, the trend of distribution and variation of the SSC is almost the same as in the rainy season. This is most evident in the phase fluctuations of the tide. The modeling results show that in the dry season, the SSC in the coastal area of Hai Phong changes in the range from 50–80 mg/l and is usually higher in river mouths and coastal areas. In ebb tide, the waters of high SSC can expand seawards and outside coastal area. The same trend is also present at low tide, but the region with high SSC extends further than in ebb tide. In the outer shore, SSC usually does not exceed 50 mg/l.

DO

DO is an important parameter representing free oxygen content in the seawater. The existence and development of marine flora and fauna depend on the dissolved oxygen in the water. The concentration of DO often relates to salinity, water temperature, water clarity, organic substances in water, and seaweed density.

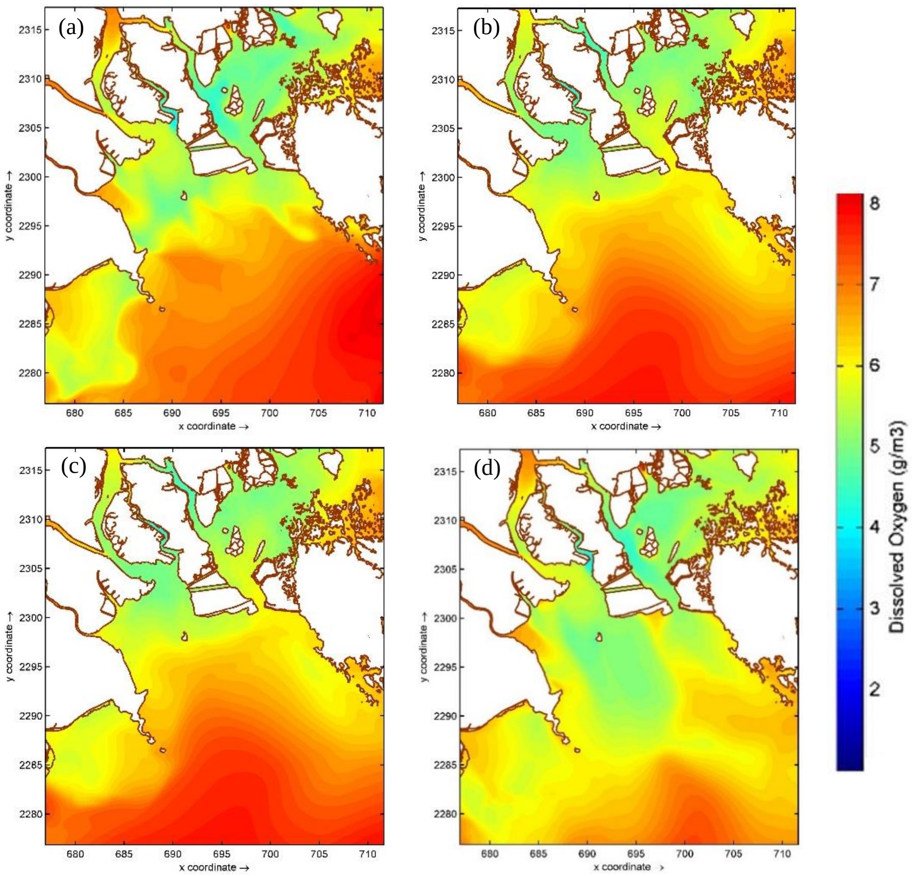

Figure 6. Distribution of DO (gO_2/m^3) on middle layer in Hai Phong coastal area, during ebb tide, in rainy season (a- present, b- kb2, c- kb5, d- kb7)

The simulation results show that in the rainy season, DO in the coastal area of Hai Phong varies widely from 5.5 gO_2/m^3 to 7.0 gO_2/m^3. As a result of the oxygen consumption processes caused by pollutants, the DO tends to be low in the interior of estuaries and coastal areas near waste sources (less than 6 gO_2/m^3) and gradually increase towards the offshore area (greater than 6.5 gO_2/m^3). The variation of the field current, as well as tidal oscillation, affects the spatial distribution of DO. During the ebb tide, the areas with a lower DO concentration extend outside the coast (figure 6b). The same trend is observed at low tide, but the lower DO zone extended outwards. In contrast, during flood tide and high tide, the area with high DO content from the sea penetrates deeply into estuaries as well as coastal areas.

In the dry season, because the areas with high pollutant concentration are limited in the estuaries and coastal areas, DO value in this area is less than in other areas, ranging within 5.5–6.5 gO_2/m^3. In contrast, in the offshore area, DO value changes from 6 to 7 gO_2/m^3. It is a result of oxygen consumption due to pollutants, the temporal and spatial distributions of DO in the coastal estuaries of Hai Phong also clearly vary according to the tidal phase. DO value increases during flood tide and at high tide. On the contrary, it is significantly reduced during ebb tide and at the low tide.

Impact of pollution load from the DVIZ on water quality in Hai Phong coastal area

COD

The scenarios with different pollution loads from the DVIZ have been established with six early scenario groups (kb1-kb6 scenarios: Increasing from 1.1 to 10.8 times between scenarios). The calculated results show that the wastewaters from DVIZ do not significantly change the distribution of COD concentration in the coastal areas of Nam Trieu - Bach Dang as well as in the coastal estuaries of Hai Phong (figures 2b, 2c). At some monitoring points near the pollution load, the increase of COD concentration is less than 0.5 gO_2/m^3. In other places, there is a very small difference between COD concentration in present and prediction simulations.

The results of the simulation during the incident, which causes a sudden increase in the waste source from the sewage treatment into the Bach Dang estuary, show that the COD value has increased markedly (1–1.5 gO_2/m^3) compared to the present (figure 2d). According to the tidal oscillations, the high COD value region develops from the discharge place to the outside (south-southwest of Cat Hai coastal area) during the ebb tide and into the rivers (Cam, Bach Dang) during flood tide. Among them, the influence of the increasing pollution load from the DVIZ in the dry season is greater than in the rainy season.

BOD

Assuming that the amount of BOD varies according to 6 different pollution loads (increasing from 1.8 to 10.6 times between scenarios), the simulation results show that the increased load of BOD slightly increases the BOD concentration with a small limitation around the discharge points (figures 3b, 3c). While far away from discharge points, there is almost no significant change in BOD concentration between the pollution load increase and the present scenario (kb1). The variation of BOD concentration around the discharge locations is also analyzed, which shows that the increase of BOD load from DVIZ only increases the BOD value in the neighboring discharge point. In the further region from the discharge points, the BOD value increases slightly compared to the present scenario. Therefore, the increase of the pollution load causes the increase in the BOD value in a small region, around the discharge location and the increase of the pollution source from the industrial zone is smaller than the pollution source from rivers and other sources.

The concentration of BOD also increases markedly when the risk occurs from the sewage tank of the industrial zone. The value of the BOD increased sharply (1–2 gO_2/m^3) around the position of discharge (figure 3d) and the regions with high BOD content developed into river mouths (Cam, Bach Dang) during flood tide. In contrast, higher BOD concentration regions expand from the discharge location to the southwest and the south of Cat Hai in ebb tide.

NH_4

The simulation results show that the influence of increasing NH_4 load (from 0.4 to 110.4 times between scenarios) causes a change of the spatial distribution and temporal fluctuation of NH_4 in this area. However, these impacts are limited to a small scale around discharge points (figures 4b, 4c). In the outer area (the area in the middle of Nam Trieu estuary), the NH_4 concentration increases to the maximum compared to the present scenario, at about 0.02 gN/m^3. In areas far from the discharge position, the NH_4 concentration descends.

Meanwhile, when pollution load increases suddenly due to the incident, the concentration of NH_4 around discharge points increases significantly (0.5–1.5 gN/m^3) compared to other scenarios. The areas with high NH_4 concentration are mainly around discharge points and expand into rivers (Cam, Bach Dang) in flood tide and towards the south-southwest of Cat Hai in ebb tide (figure 4d). These results show that the concentration of NH_4 exceeds the values in 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 areas.

PO_4

When PO_4 load from the DVIZ to the coastal area increases (0.8–77.7 times between scenarios), it causes the slight rise of PO_4 in the coastal area of Hai Phong. However, the scope of the influence of PO_4 is quite small, only evident near discharge point, and does not considerably affect the Hai Phong coastal area (figures 5b, 5c).

Analysis of simulation results from different scenarios in some locations around the discharge source indicates that when the amount of PO_4 load from the DVIZ into Nam Trieu estuary increases, the value of PO_4 increased in the relatively small range near the discharge position. The results of the PO_4 concentration at some monitoring points in the middle channel of Nam Trieu river mouth indicate that the increasing pollution load of DVIZ only greatly increased PO_4 concentration (0.02 gP/m^3) in the middle Nam Trieu mouth. Although the pollution load from DVIZ causes an increase of the concentration value in some places (kb2 to kb6), this increase does not significantly impact the PO_4 concentration at the coastal estuary of Hai Phong.

With an increase in the pollution load in case of an incident, the value of PO_4 concentration in the area around the discharge position increases sharply compared to present condition and other scenarios (0.02–0.04 gP/m^3). The high PO_4 value region varies with tidal oscillation and influences Nam Trieu river mouth and Cat Hai coastal area (figure 5d). According to the QCVN 10-MT:2015/ BTNMT for PO_4 (0.2 gP/m^3 for aquaculture areas and 0.5 gP/m^3 for other areas), the increase of PO_4 in this situation is still within the allowable limits.

Suspended sediment

The simulation results show that although suspended sediment from the industrial zone increases (kb1-kb6 scenarios), its impacts on the distribution and variation of SSC in the Hai Phong coastal area are insignificant. The suspended sediment from DVIZ only increases SSC at the area with a small scale around the discharge point, especially in the results of scenarios from kb2 to kb6. The increase of SSC due to the discharge load from DVIZ is quite small in the further area from the discharge point.

In the case of an incident, the SSC around discharge point increases clearly (10–15 mg/l). The areas affected by discharge point from the industrial zone are the entire water area around the discharge site, neighboring area, inside rivers (Cam, Bach Dang), and Cat Hai coastal area. The concentration of suspended sediment in these areas exceeds the QCVN 10-MT:2015/ BTNMT for suspended sediment (50 mg/l for aquaculture areas and other areas).

DO

The simulation results show that the increase of pollutant load (kb1-kb6 scenarios) causes a decline of DO near the discharge point; in the further area from discharge point, the effect of DO depletion is smaller. As a result, the effect of waste sources is quite small with a limitation scale around the discharge point (figures 6b, 6c). The influences due to the decline of DO are also analyzed and assessed at monitoring points outside the discharge site. The results show that the DO does not differ considerably between the different calculation scenarios. Therefore, the effect from DVIZ on DO is very small, limited only near the discharge point.

The increase in pollution load due to the risk can significantly decrease the concentration of DO in the waste site. DO values decrease from 0.2–1.0 gO_2/m^3 (figure 6d). The area with lower DO occurs around discharge points and rivers (Nam Trieu, Cam, Bach Dang) in the flood tide and the Cat Hai coastal area. Compared with the QCVN 10:2015/BTNMT (5 gO_2/m^3 for aquaculture areas and other areas), the water quality around the discharge position sometimes reduces and is lower than the allowable value.

Discussion

In the present scenarios, when the Nam Trieu estuary receives wastewater from DVIZ, the concentrations of nutrients and organics do not have a significant difference with the outer area and Bach Dang - Nam Trieu estuaries. The effect of discharge sources from the industrial zone is not larger than other sources, especially sources from rivers (Cam, Bach Dang). According to the study results in the Ha Long bay with 3D model [17], the pollutants (nutrients and organics) which were brought from Hai Phong coastal area had a great impact on the water quality in the west part of Ha Long bay rather than pollutant sources from shore into the bay. Many involved studies also showed that the pollutant sources from a few points of pollution on shore caused a decline of water quality locally, while other sources from the continent affected the water quality of the coastal region with a wider range [18–20].

According to the QCVN 10:2015/BTNMT for the concentration of nutrients, SSC and QCVN 10:2008/BTNMT for COD, at some time (ebb tide and flood tide), the concentration of nutrients and organics has exceeded the allowable limit in the present condition. The results of forecast scenarios due to the increase of discharge point from DVIZ (kb1-kb6 scenarios) witness an increase in the concentration of nutrients, organics, suspended sediment that caused local pollution in the area. While, in the case of the risk, the effect of pollution load from DVIZ become more pronounced to Bach Dang estuary. In this situation, the concentration of nutrients and organics increases significantly compared to the present condition. Most of them have exceeded the permissible standard (NH_4, COD, BOD, suspended sediment) and cause a decreasing DO concentration. Thus, in all scenarios, these pollutants cause local contamination (Nam Trieu mouth, Cam, Bach Dang estuaries, and coastal area of Cat Hai), debilitating water quality in some areas near the pollution source with the scale varying according to tidal oscillation. This can be explained by the peculiarity of the hydrodynamic regime in the Nam Trieu estuary that receives waste sources and is affected by the tide and discharge of large rivers [9, 10]. This region is also open sea, so in the flood tide, the seawater enters the coastal area and dilutes pollutants in this area, leading to the improved water quality. The mechanism relates to the role of the tide in the ability of exchanging water [21], increasing transportation, transferring pollutants, reducing local pollution in the coastal estuaries, which are affected by the tide [22, 23].

CONCLUSIONS

To assess the impact of pollutant sources from DVIZ on Bach Dang estuary in particular and Hai Phong coastal area in general, a system of hydrodynamic-water quality model for Hai Phong coastal area was set up with several different scenarios (present and increasing pollution source). The simulation results show that the Delft3D is an effective model to simulate and forecast the effects of pollutant sources on the water quality in this study.

The spread and dispersion of contaminants (nutrients, organics, and suspended sediment) depend on the discharge load and hydrodynamic regime in the area. In case of the increase in waste concentration but with control of the discharge, the impact of pollutants is limited to a small scale around discharge point, meanwhile the effects on Nam Trieu estuary and other areas are quite small. By contrast, when discharge is increased strongly due to the risk of wastewater treatment (kb7 scenario), the pollutants from DVIZ cause the significant increase in the concentration of contaminants in this area, most of which have exceeded the permissible standards (such as NH_4, COD, BOD, suspended sediment), and DO decreased (0.5–1 gO_2/m^3). The range of influenced region extends from the pollution source point to the Nam Trieu estuary, into the Cam and Bach Dang rivers, and Cat Hai coastal area.

With the main objective of assessing the impact of the waste source from DVIZ on water quality of Hai Phong coastal area, this study only considers discharge sources from the continent through rivers and from pollution source of DVIZ. Several other pollution sources were not taken into account in this study. This restriction should be corrected in the next research.

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