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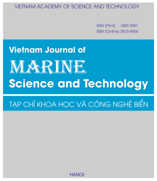

The interaction of tide and river flow on water quality in Hai Phong coastal waters (Lach Huyen - Do Son) drawn from field observation

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ABSTRACT

This paper presents the results of a study on the impacts of the interaction of tide and river flow on water quality at the Hai Phong coastal water, outside the Nam Trieu estuary and Lach Huyen, drawn from field observation from October 14, 2022, to October 17, 2022. During the field observation, the dissolved oxygen concentration was measured, and water samples were taken at the surface, mid-depth, and bottom of 8 observational points at 1:00, 7:00, 13:00, and 19:00 h. Five sewage wastewater samples at Do Son coast and 6 coastal and river water samples were also taken. The collected seawater samples were laboratory analyzed to determine the concentration of BOD_5, COD, TN, and TP. Additionally, the concentration of ions NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-} are determined by analyzing collected coastal, river, and sewage water samples and seawater samples at mid-depth at all observational points in a laboratory. It was found that the concentration of essential nutrients and other environmental components in wastewater samples generally does not exceed those specified in Vietnam regulations. The discharge of wastewater during the field observation was minimal. Thus it could be expected that the wastewater would not have a notable influence on seawater quality in the marine study area. Consequently, the study area's primary source of nutrient pollutants was rivers. Time variation of the concentration of environmental components reveals that the nutrient concentration in the marine study area strongly influences by the interaction of the tide and river flow. The concentration of dissolved oxygen and major nutrient components in seawater at 8 points was within the limit of Vietnam standard for coastal water. However, significant nutrient concentration exceeds thresholds for eutrophication.

Keywords: Nutrient pollution, nutrient concentration, tidal and river influence, estuarine water, eutrophication.

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INTRODUCTION

A marine area outside an estuary is one of the most complex but productive environmental and ecological systems. In some cases, the marine area outside an estuary can be considered an extended part subject to marine (tides, waves, saline water) and riverine influences (freshwater, sediment, nutrients, and other pollutants). Under the influence of saline water, riverine suspended sediment together with pollutants is flocculated and deposited. Thus yielding high nutrient and other pollutant concentrations in the water column [1–3]. Due to continuous changes in tidal and other hydrodynamic conditions, sediment and pollutant transport processes fluctuate significantly with time [4–7].

The sea area outside Nam Trieu estuary and Lach Huyen provides many environmental services for the sustainable socio-economic development of Hai Phong city. Besides providing a busy marine transport route for almost all goods exported from North Vietnam, the sea has beautiful and busy recreational beaches and critical coastal ecosystems, such as tidal flats, mangroves, and coral reefs [8–12]. Socio-economic activities in the land area surrounding this sea area and upstream of rivers pouring into the sea include tourism and recreation, urban development, port and marine transport, and industry. In recent years, due to socio-economic development, a large amount of untreated wastewater has been discharged to the rivers upstream of the estuaries and directly to the sea. Additionally, uncollected solid wastes are discharged directly into the sea and rivers or are washed into the sea and rivers by overflow rainwater [13]. The solid wastes and wastewater discharged to rivers are finally carried to the sea by river flow. Pollutants from wastewater and solid wastes make the seawater quality of the estuary and adjacent marine area continuously degraded [13–25]. The most important pollutants in the sea area are nutrients and plastic wastes [13, 14, 19–25]. Pollution has caused significant damage to coastal ecosystems and hinders sustainable socio-economic development of residents who rely on using and extracting marine and coastal resources [13–19, 25]. Understanding water quality characteristics in the marine area outside an estuary helps minimize pollution damage and improve the health of ecosystems and restore environmental conditions for socio-economic activities. Especially, data on the spatial and temporal variation of seawater environmental parameters in the marine area can also be used for scientific research on the environmental and hydrodynamic processes under the strong interaction of tide and river flow in a marine area adjacent to a river estuary [4–7].

Many studies have shown river flow and tide interaction in the marine and estuarine areas [26–28]. However, this research is only based on numerical models. Based on field survey data, systematic research still needs to be done on the interaction between river flow and tide in marine area.

With the above facts, this paper aims to present environmental data obtained during a field observation in the marine area outside Nam Trieu estuary and Lach Huyen. The field observation was conducted by the Research Project "Research, development of a software for the computing and forecasting marine pollutant transport for supporting management decision making", ID TNMT.2021.02.01. The purpose of the field observation is to provide data for the validation of a numerical model on the computation and forecast of pollutant transport in a marine environment.

MATERIAL AND METHOD

This research uses data obtained from laboratory analysis of seawater samples, coastal and riverine water samples, and wastewater samples taken during a field observation carried out from 13:00 on October 14, 2022, to 13:00 on October 17, 2022, at the coasts and eight observation points in the sea, shown in Figure 1. Coordinates of the observation points are presented in Table 1.

During the field observation, the study area had fine weather, no rainfall, and a North-East wind velocity of about 2 m/s. In addition to surface wave and sea current measurements, at each observational point, the dissolved oxygen (DO) concentration was measured, and 288 seawater samples were taken at three levels: surface, mid-layer, and bottom four times per day: 1:00, 7:00, 13:00, and 19:00 h from 13:00 Oct. 14, 2022, to 13:00 October 17, 2022. The method for sampling seawater at different depths follows National Standard TCVN 5998:1995 and ISO 5667-9:1992 [29]. Equipment for seawater sampling at different depths is Wildco, USA. In addition to 288 seawater samples, five wastewater samples were taken at the coasts of Do Son, and seven water samples were taken at the coasts, river mouth, and inside a river. Besides DO concentration, pH, turbidity, and salinity were measured at these locations using the portable HACH HQ440d equipment. The collection time for this kind of sample differs for different locations as the survey team moved along the coasts and river to find appropriate sampling locations. Details on the locations of wastewater or water samples are presented in Table 2.

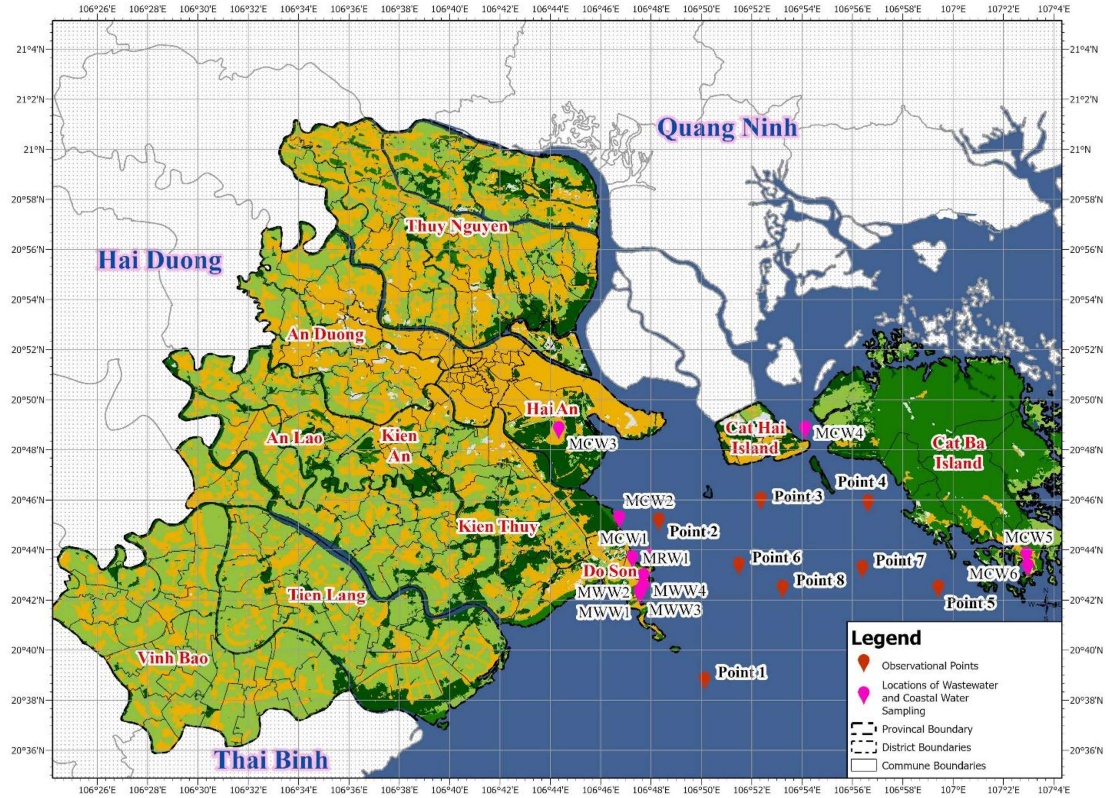

Figure 1. Observation points

Table 1. Coordinates of observation points

No.	Point name	Coordinates of observation points	
1	Point 1	106.8353576°E	20.6399161°N
2	Point 2	106.8051684°E	20.7459208°N
3	Point 3	106.872702°E	20.759729°N
4	Point 4	106.943608°E	20.757998°N
5	Point 5	106.990180°E	20.701179°N
6	Point 6	106.858117°E	20.716367°N
7	Point 7	106.939880°E	20.714307°N
8	Point 8	106.887113°E	20.701118°N

Table 2. Locations of wastewater and coastal water sampling

Point index	Location	Type of samples	Sampling Time
MWW1	Near Ben Thoc seafood restaurant	Sewage	2:04 PM Oct. 14, 2022
MWW2	Near Thanh Phong restaurant	Sewage	2:13 PM Oct. 14, 2022
MWW3	Near Hoa Lan restaurant	Sewage	2:26 PM Oct. 14, 2022
MWW4	Near Hai Yen nursing and rehabilitation center	Sewage	2:39 PM Oct. 14, 2022
MWW5	Near Trade union training and conference center	Sewage	2:58 PM Oct. 14, 2022
MCW1	A Lach Tray river branch	Estuarine water at the mouth of a river branch	3:32 PM Oct. 14, 2022
MRW1	Inside a Lach Tray river branch	River water (mainly sewage) behind a gate in a river branch	8:12 PM Oct. 15, 2022
MCW2	Opening Tan Thanh Sluice Gate	Estuarine water in front of Tan Thanh sluice gate, Cau Rao river	9:23 AM Oct. 15, 2022
MCW3	Cau Rao river sluice gate, near Thuy Giang commune culture house	Estuarine water	10:15 AM Oct. 15, 2022
MCW4	Got ferry wharf, Cat Hai	Seawater	10:50 AM Oct. 15, 2022
MCW5	Cat Ba tourism wharf	Seawater	9:12 AM Oct. 16, 2022
MCW6	Cat Co 3 beach	Seawater	10:03 AM Oct. 16, 2022

Table 3. Methods for determining environmental components in water samples

Environmental component	Methods for analyzing water samples to determine environmental components
BOD_5	Simon et al [31]
COD	Vietnam Standard TCVN 6186:1996 [32]
COD (wastewater)	Vietnam Standards TCVN 6491:1999 [33]
TN	Vietnam Standard TCVN 6638: 2000/ISO10048: 1991 [34]
TP	National Standard TCVN 6202:2008/ISO 6878:2004 [35]
NH_4^+	SMWW - 4500 NH_4^+–F [36]
NO_2^-	SMWW - 4500 B [36]
NO_3^-	Vietnam Standard TCVN 6180:1996 [37]
PO_4^{3-}	National Standard Standards TCVN 6202:2008 [38]

After being sampled, seawater sample were preserved and handled following National Standard TCVN 6663-3:2016 and ISO 5667-3:2012 [30]. All seawater samples were analyzed in the laboratory of the Vietnam Natural Resource and Environment Technology Investment and Development Joint Stock Company to determine the concentrations of BOD_5, COD, TN, and TP. Water samples at mid-depth were also analyzed to determine the concentration of ions NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-}. Coastal and wastewater samples were also analyzed to determine the concentration of ions NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-}. Methods for analyzing water samples to determine environmental components are presented in Table 3.

RESULTS AND DISCUSSIONS

Concentration of pollutants and other environmental components of wastewater and coastal water

The concentration of pollutants and other environmental components of wastewater and coastal water in the study area is presented in Table 4.

Table 4. The concentration of pollutants and other environmental components of wastewater and coastal water in the study area

Point index	Environmental components							
	Turbidity (NTU)	pH	DO (mg/L)	Salinity (‰)	NO_3^- (mg/L)	NO_2^- (mg/L)	NH_4^+ (mg/L)	PO_4^{3-} (mg/L)
MWW1	8.29	7.18	2.27	5.49	24.780	1.0100	4.2580	0.1857
MWW2	20.90	7.24	0.65	3.35	4.224	0.0627	0.0834	0.6392
MWW3	29.40	6.54	0.22	0.20	1.468	0.0954	0.5123	0.8319
MWW4	41.20	6.88	2.45	4.60	0.6431	0.0516	46.2200	0.4097
MWW5	0.60	7.00	3.61	4.90	22.140	0.0254	32.0400	0.7832
MCW1	40.20	6.22	9.91	17.42	1.522	0.0203	0.4995	0.2142
MRW1	8.08	7.29	0.59	3.31	5.260	0.0330	18.8400	0.2309
MCW2	38.28	6.98	7.20	17.24	2.117	0.0382	0.0954	0.1327
MCW3	11.13	6.98	6.75	14.32	0.376	0.0887	0.1385	0.1160
MCW4	7.52	6.80	7.46	22.80	3.042	0.0108	0.0954	0.0697
MCW5	3.19	6.98	5.76	31.10	1.476	0.0442	0.0787	0.0382
MCW6	3.65	6.96	7.71	31.50	2.465	0.0107	0.0179	0.0308

As shown in Table 3, the concentration of important nutrients and other environmental parameters in wastewater samples varies considerably between samples. Investigation during the field survey revealed that the wastewater originated from restaurants and other recreation/professional facilities in the area. By comparing the determined concentration of important nutrients and other parameters in wastewater samples with the corresponding values in the National technical regulation on domestic wastewater [39], it can be found that the concentration of essential nutrients and other parameters in wastewater samples, in general, is well below those specified in Vietnam regulations. It was observed during the field investigation that the wastewater discharge was minimal. Also, the wastewater was mainly from washing foods before processing or dish wash. The sewage discharge is low because the survey time was low for tourism and the dry season. With slight discharge and low concentration of pollutants, it could be expected that the wastewater discharge during the field survey would not have a notable influence on the seawater quality in the adjacent sea. However, during a high tourism season, the wastewater discharge is large, and its contribution of wastewater to the pollution of seawater can be notable.

The river water sample MRW1, taken behind a gate in a Lach Tray River branch, is mainly sewage; thus, why the concentration of major nutrients in this water sample is very high, as shown in Table 4. With high nutrient concentrations, the water from this river branch can influence the coastal water locally when the gate is open.

The estuarine water sample MCW1 was taken at the mouth of the above-mentioned Lach Tray River branch during low tide. It can be seen from Table 4 that the nutrient concentration in this water sample is higher than the limit in the National standard for marine water [40]. Other estuarine water samples (MCW2, MCW3, MCW4) or coastal water samples (MCW5 and MCW6) have nutrient concentrations lower than the limit in the National standard for marine water [40]. The low concentration may be explained by the fact that all these samples are taken during the high tide phase.

During the field observation, the survey team did not investigate the wastewater from Cat Hai Island, which has three communes with more than 10,000 people. However, with a relatively small population, it is expected that the wastewater from this island has a limited influence on the water quality of the study sea area. On the other hand, the coast of Cat Ba island, which borders the study sea area in the East direction, is mainly covered with mangrove forest and forest; thus, the wastewater discharge from this coast is expected to be small.

The MCW1 water sample was taken at the mouth of the closed estuary of a Lach Tray River Branch, a fish harbor adjacent to a fish market. The water at this location has high turbidity due to the action of waves on a muddy flat beach. It can be seen from Table 3 that even with high turbidity, NH_4^+, and PO_4^{3-} ion concentrations in this water sample are in the range of water suitable for swimming, water sports, and another purpose specified in the National technical regulation on marine water quality [40]. The relatively high nutrient concentration in this water sample might be due to wastes from fishing vessels, the fishing market, together with wastewater from the closed part of the river branch. The MRW1 water sample was taken at the closed dam of the estuary of a Lach Tray River Branch, having a relatively stationary water body that can be considered a receiver of wastewater from the banks of the river branch. Thus, the concentration of nutrient components in the water sample is significantly high, as shown in Table 4.

The concentrations of NH_4^+ and PO_4^{3-} ions in coastal water samples from MCW2 to MCW6 have values close to or well below the values for aquaculture and bio-conservation, specified in the National technical regulation on marine water quality [40]. However, except for the water sample at Cat Co 3 (sample MCW6), the concentration of primary nutrients in samples from MCW2 to MCW5 is higher than the thresholds for eutrophication [41–46], meaning that the water needs improvement to be suitable for supporting healthy coastal ecosystems.

Concentrations of pollutants in the seawater and relation with the tide and river flow

The tide and river flow strongly influence current and pollutant transport in a coastal sea outside an estuary. Therefore, to understand the time variation of pollutant transport in the study area, it is necessary to understand the time variation of the tide.

Figure 2 presents the time variation of the tidal water level at Hon Dau station. It can be seen in this figure that the tide in this area is a diurnal tide with a tidal height of approximately 3 m, suggesting that the influence of the tide on pollutant transport can be enormous.

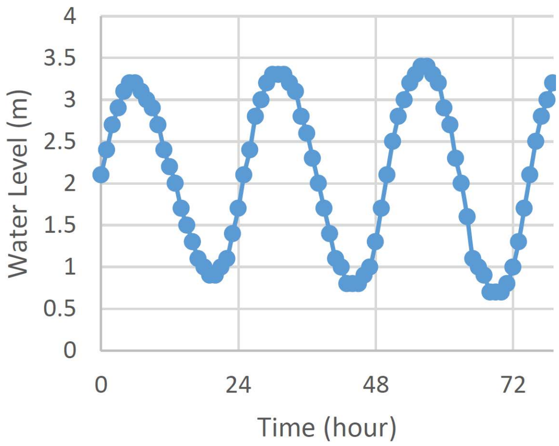

Figure 2. Tidal water level at Hon Dau from October 14 to October 17, 2022

Figs. 3a–h respectively present the time variations of DO concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points from 13:00 October 14, 2022, to 7:00 October 17, 2022. It can be seen from the figures that the DO concentration changes significantly during the day, attaining maximum value during the daytime and minimum value at night. DO concentration also notably changes with depth and attains the maximum value at the water surface and the minimum value at the bottom. The DO concentrations are highest at points 1 and 5 (most offshore points) and have smaller values at inner points. Like other environmental components, the tide and river flow should strongly influence the DO in water. However, as shown in Figs. 3a–h, there is only a slight difference in DO concentrations between different observational points. This phenomenon might be because the DO concentration in seawater depends mainly on the photosynthesis of phytoplankton and BOD, COD concentration. As wind velocity during the observation is moderate, oxygen exchange between the air and the surface water is extensive. It is noted that the value of DO concentration and its variation in space and time in this research is similar to that in other research [15–16, 21, 47–48].

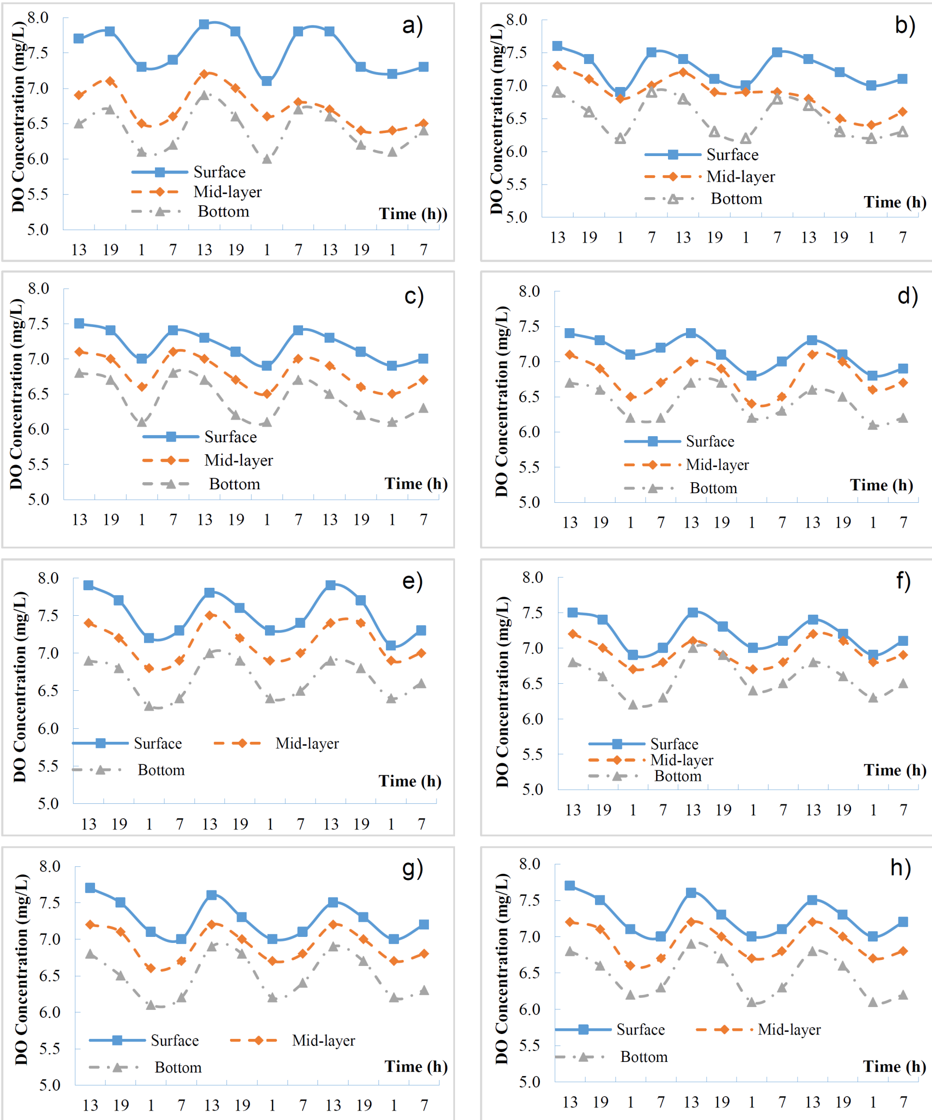

Figure 3. Time variation of DO concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

Figs. 4a–h present the time variation of BOD_5 concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points. As seen in the figures, the change in BOD_5 concentration changes similarly to the tide. The BOD_5 concentration during flood tide has lower values compared to that during the ebb tide. The BOD_5 concentrations at offshore measurement points are larger than at inner points. As a tidal period is only one day, during a tidal period, a change in BOD_5 concentration due to biodegradation is relatively small. Thus the BOD_5 concentration in the study area is mainly influenced by dynamical processes caused by the interaction between tide and river flow. During flood tide, the clean seawater with low BOD_5 concentration infiltrates into the study area and lowers the BOD_5 concentration. The influence of clean offshore seawater decreases in the land direction, causing an increase in the BOD_5 concentration from offshore to onshore. During ebb tide, relatively more polluted river water extends the influence area to the sea direction, thus causing an increase in BOD_5 concentration at all measurement points. Points located in the North direction of the study area during ebb tide have very little influence from the seawater and thus have a relatively homogeneous BOD_5 concentration. On the other hand, points near the offshore border (points 1 and 5) have an intense mixing with the clean offshore seawater, thus having lower BOD_5 concentration. The spatial and temporal distribution of BOD_5 in the study area is similar to that of other estuaries in the world (47, 48).

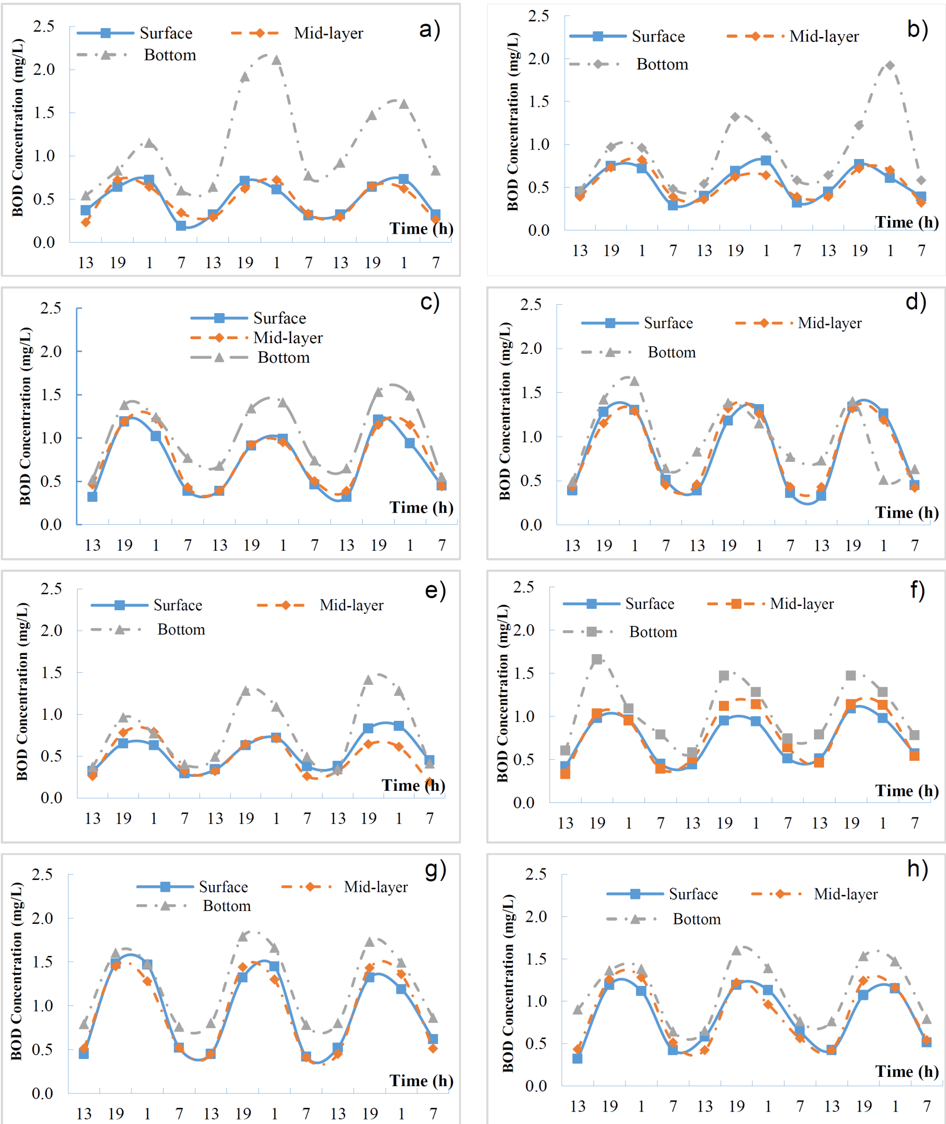

Figure 4. Time variation of BOD_5 concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

The time variation of COD concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points is presented in Figs. 5a–h. It can be seen in Figs. 5 that the COD concentration is significantly higher than that of BOD_5. At some measurement points, COD concentration approaches DO concentration, especially during ebb tide. Thus, available COD can potentially deplete the dissolved oxygen in water samples, especially during unfavorable weather conditions.

The influence of the tide and river flow on COD is similar to that of BOD_5, and COD increases at all measurement points during the ebb tide and decreases during flood tide.

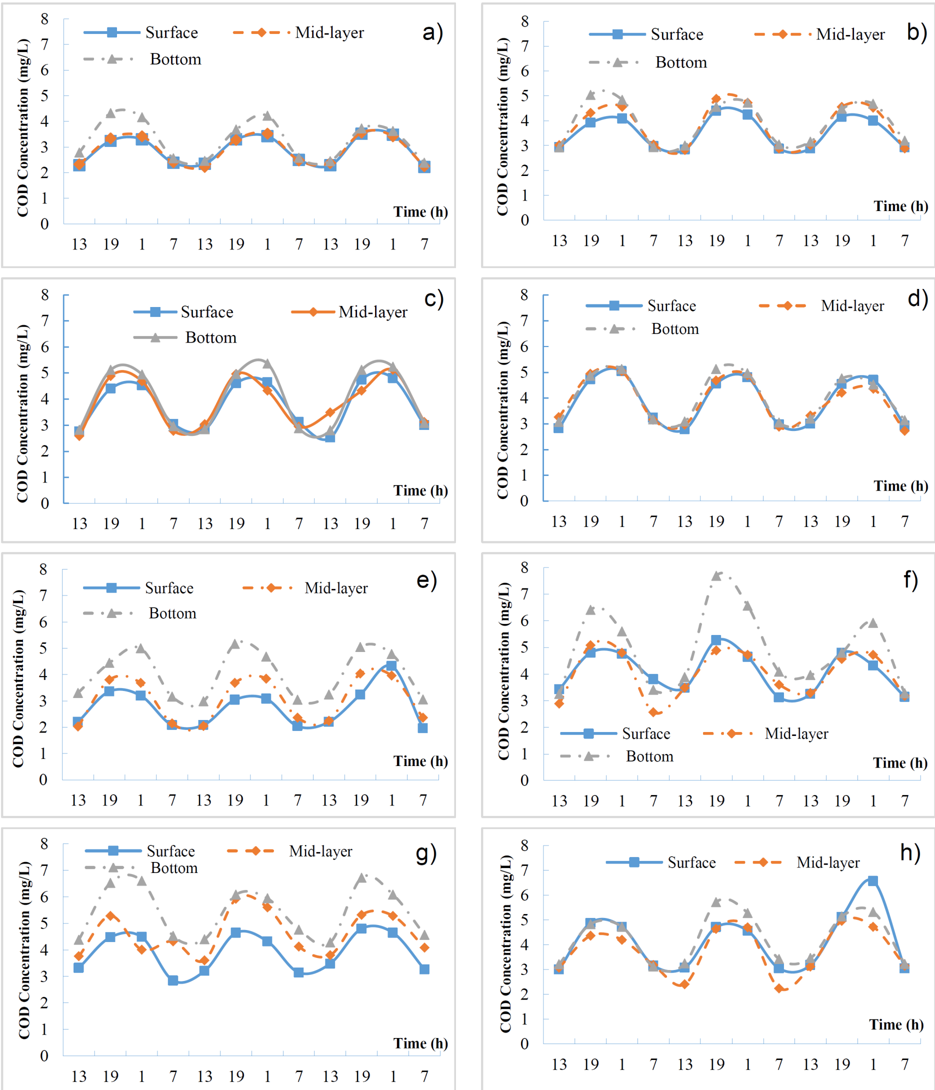

Figure 5. Time variation of COD concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

The total nitrogen concentration in seawater represents the sum of organic and inorganic nitrogen compounds concentration. Total nitrogen concentration is an essential environmental parameter for assessing the pollution of a marine area. In general, for seawater, nitrogen is the limiting nutrient for algae growth [45]. Excessive nitrogen concentration can lead to an algal bloom, seriously impacting on aquatic and human life. Toxic species of algae can cause stress or kill aquatic and terrestrial animals. The decomposition of dead algae and other organic pollutants and algae respiration can deplete oxygen in seawater, causing stress or killing fish and other aquatic organisms, forming dead zones in coastal water.

The total nitrogen in seawater in the study area is presented in Figs. 6a–h. Compared with the thresholds of nitrogen for eutrophic water [41–46], it can be seen from the figures that the total nitrogen concentration in seawater in the study area generally exceeds the level for eutrophication, meaning that excessive algal growth is expected. Eye observation by the authors of this paper reveals that the water in the study area is green, meaning that excessive algal growth has happened in the marine area.

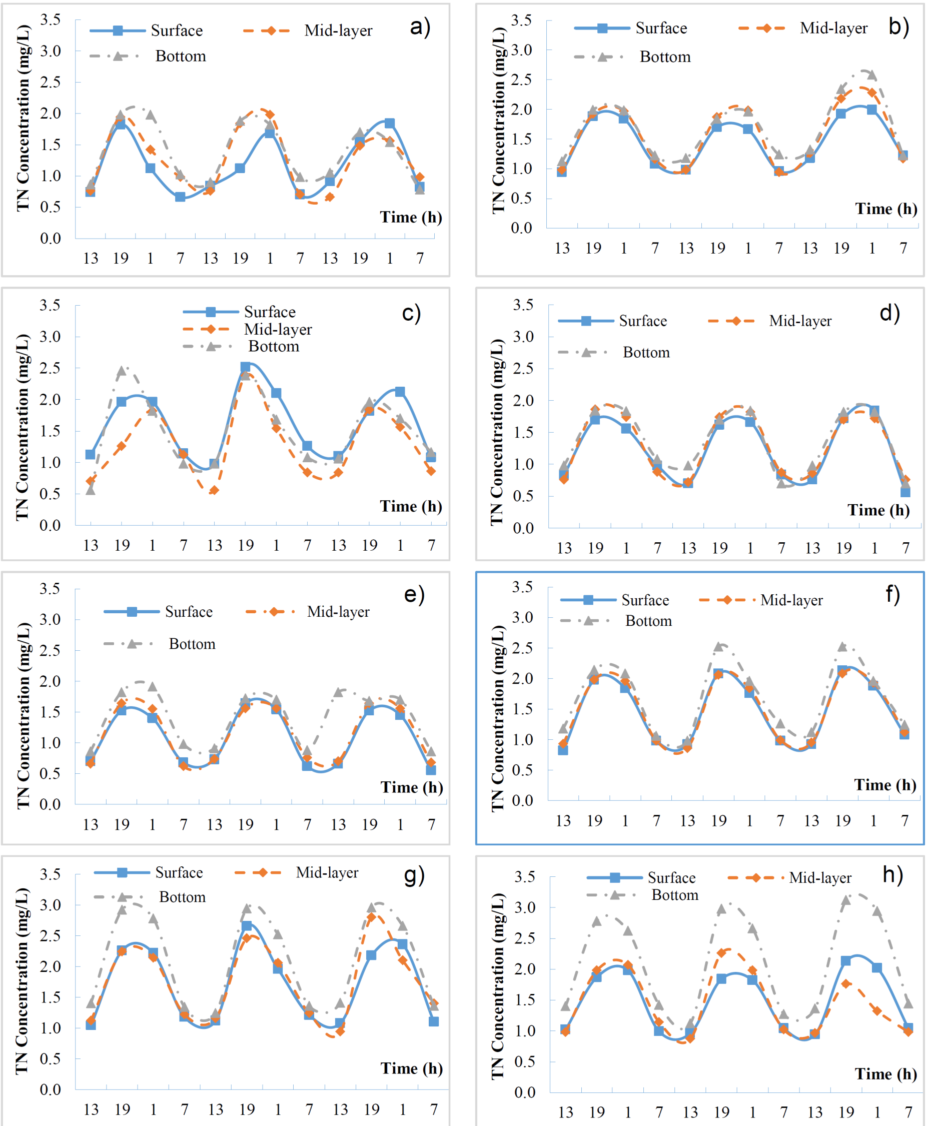

Figure 6. Time variation of TN concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

It can be seen in the figures that, similar to other environmental components, the total nitrogen concentration in seawater in the study area is also strongly influenced by the tide and river flow. A low concentration of total nitrogen concentration is observed during flood tide, while a high concentration of total nitrogen concentration is observed during ebb tide. Only when the intrusion of offshore seawater is strong during flood tide the concentration of total nitrogen is lower than the threshold for water eutrophication.

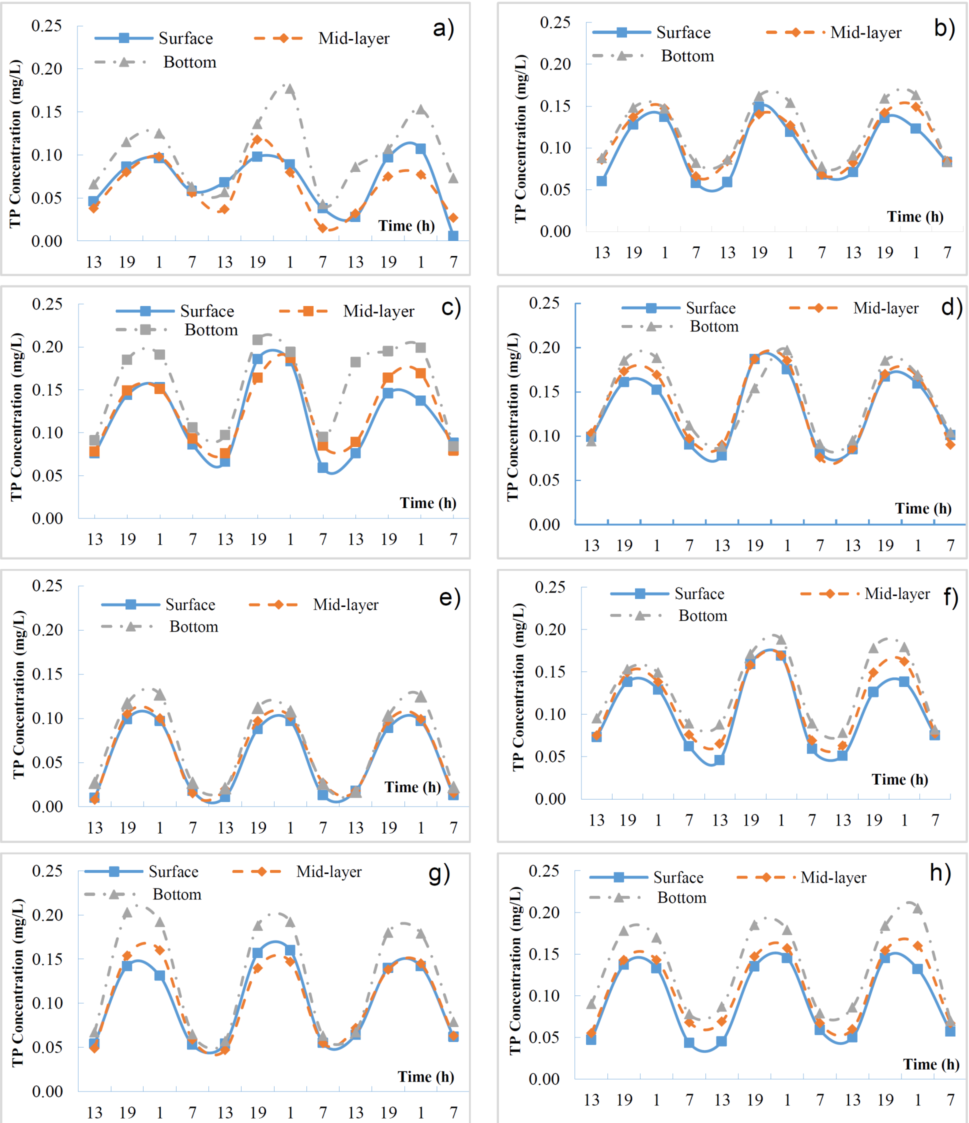

Figure 7. Time variation of TP concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

Figs. 7a–h presents the time variation of TP concentration at three levels (surface, mid-depth, and bottom) of 8 measurement points. Compared with the thresholds of phosphorus concentration for eutrophication in seawater [41–46], it can be seen from the figures that the TP concentration in seawater in the study area exceeds the level of eutrophication. Thus, the seawater in the study area is not only eutrophic concerning nitrogen and phosphorus. Like nitrogen, phosphorus is also a limiting factor for algal growth in seawater, especially in cases of high nitrogen concentration.

The time variation of total phosphorus concentration, shown in Figs. 7a–h, reveals that the phosphorus concentration in the study area also has a very strongly relates with the tide and river flow.

In research on the environmental status of a water body, knowledge of the concentration of nutrients, such as ions NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-}, is of the most importance. Almost all cases, the concentration of the nutrients above-mentioned is used to assess eutrophication for seawater. However, due to a limitation in the budget, only the concentration of NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-} ions at the mid-depth level of 8 observational points is determined.

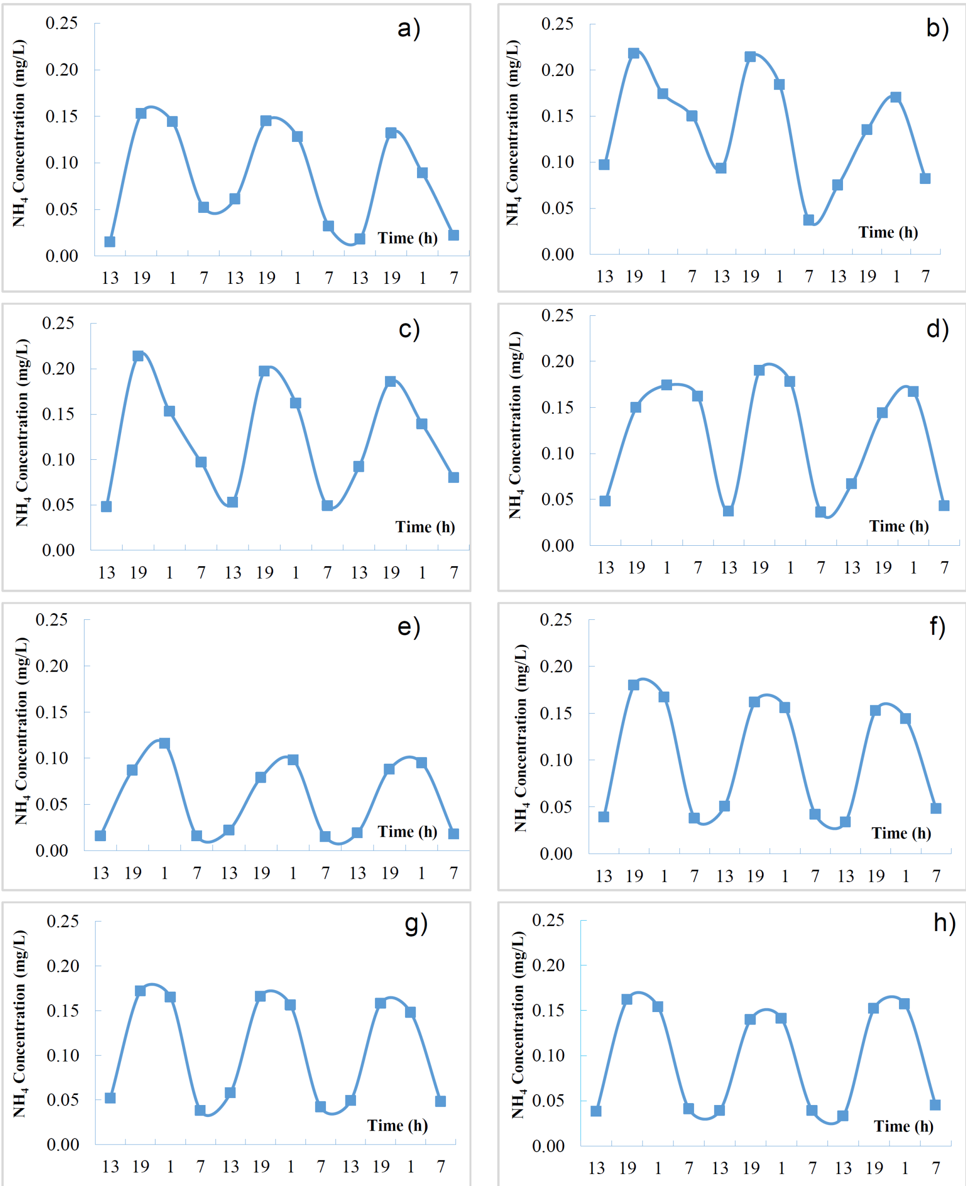

Figure 8. Time variation of NH_4^+ ion concentration at mid-depth of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

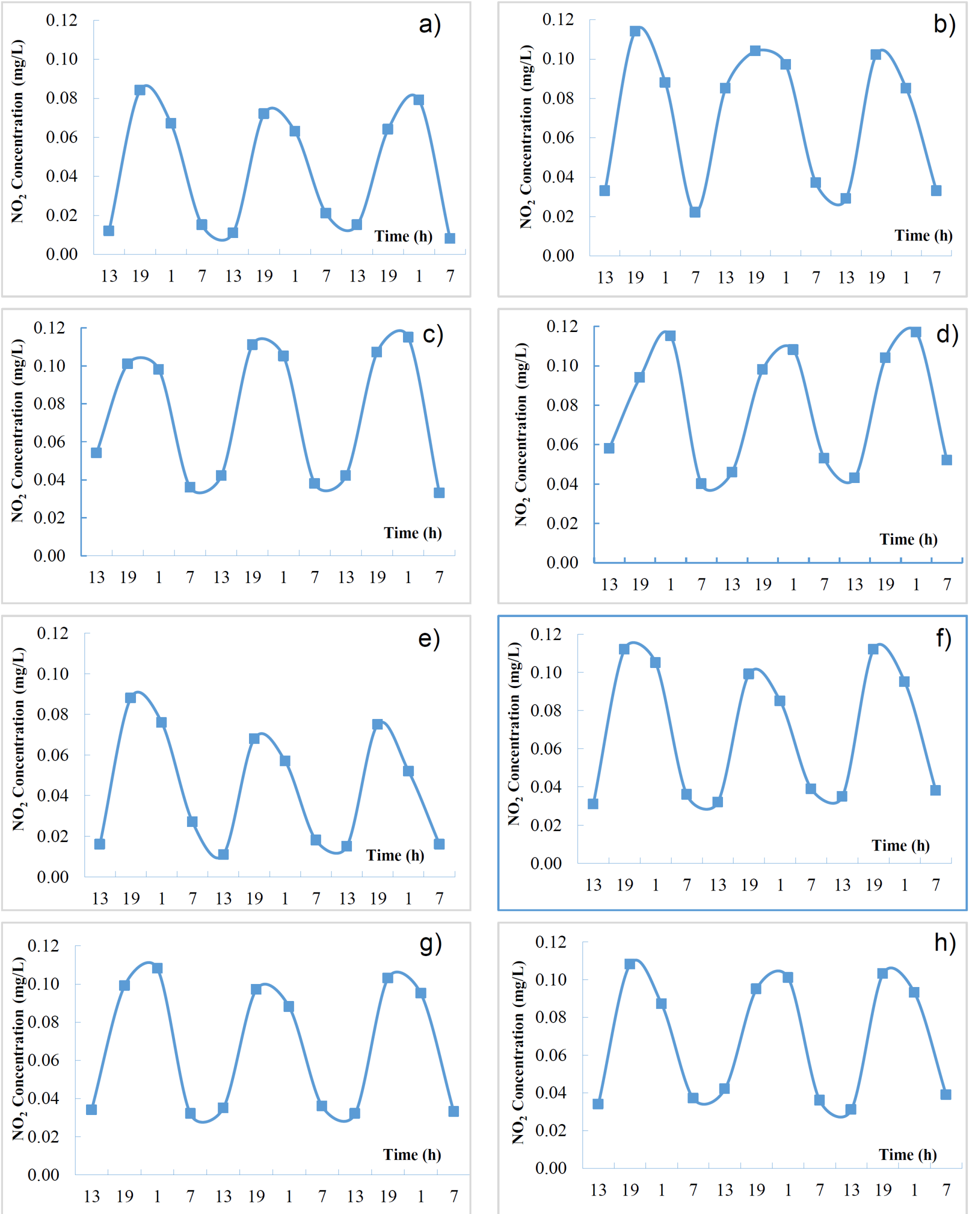

Figure 9. Time variation of NO2- ion concentration at mid-depth of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

Figures 8–11 respectively show the time variation of NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-} ions at the mid-depth. Similar to Figure 3 to Figure 7, Figures 8–11 show that the concentration of NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-} nutrients at the mid-depth at all stations are strongly influenced by the tide and river flow; and lower values of nutrients are observed during the flood tide, while high values of nutrients are observed during the ebb tide.

Compared with the Vietnam National technical regulation on marine water quality [20], Figs. 8–11 show that the concentration of major nutrients in seawater in the study area is within limits for recreation and aquaculture use. However, by comparing with thresholds for eutrophication [26], only during the flood tide, at some observational points, the concentration of major nutrients is lower than the limit for eutrophication.

From the data on nutrients and other environmental components in the Hai Phong seawater outside the Nam Trieu estuary and Lach Huyen, and in the wastewater in this research and related research [11, 14–16, 49, 50], the nutrient pollution in the study area is mainly from the upstream rivers. Thus, to eliminate eutrophication and improve the health of ecosystems in the study sea area, it is necessary to do ridge-to-reef integrated coastal management, including collecting and treating wastewater and solid waste upstream of rivers [51].

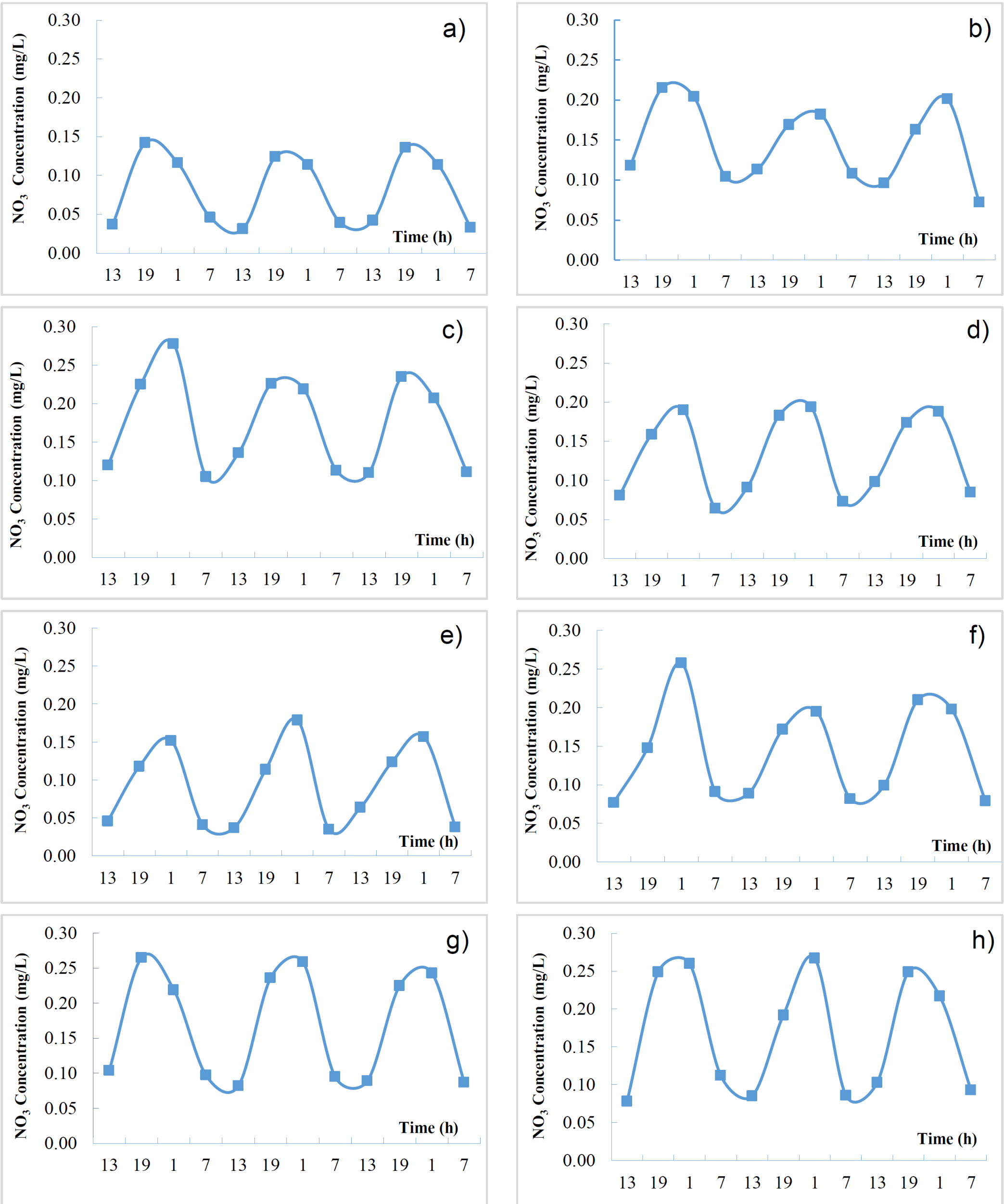

Figure 10. Time variation of NO_3^- ion concentration at mid-depth of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

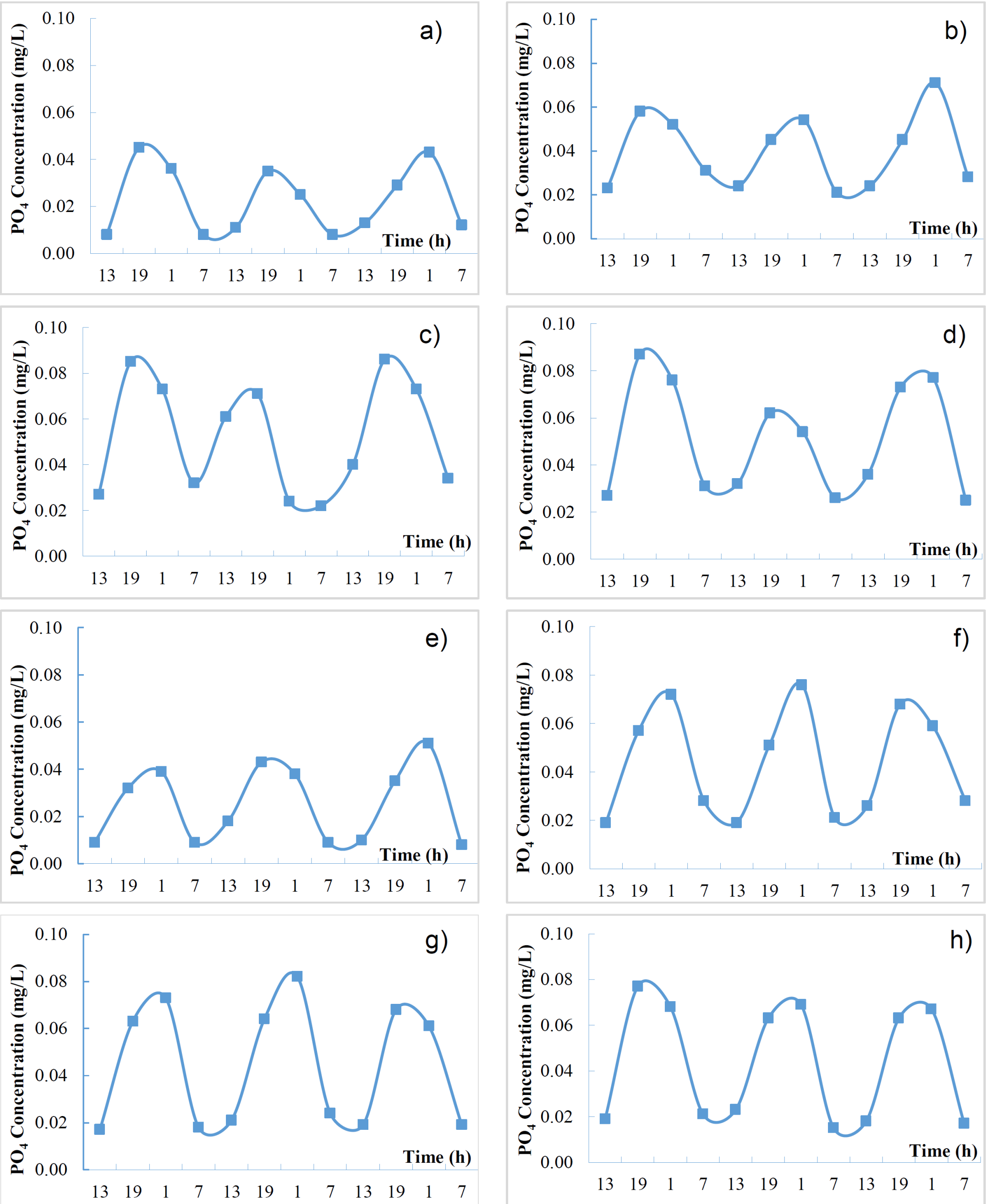

Figure 11. Time variation of PO_4^{3-} ion concentration at mid-depth of 8 measurement points: a) point 1, b) point 2, c) point 3, d) point 4, e) point 5, f) point 6, g) point 7, and h) point 8

CONCLUSION

From the data obtained during a field observation in the Hai Phong Sea area outside Nam Trieu Estuary and Lach Huyen, it is possible to draw the following conclusions:

1) Concentration of nutrients in wastewater from Do Son peninsula during the survey period from October 14, 2022, to October 17, 2022, is within limits in the National technical regulation on domestic wastewater. With low discharge during the low

tourism and dry seasons, it is expected that during the field observation, the wastewater does not have a notable influence on the seawater in the study area.

2) Concentration of major nutrients and other environmental components in seawater in the study sea area during the survey mentioned above period shows that the study sea area has relatively good water quality, suitable for recreation and aquaculture use and bio-conservation; however, it exceeds limits for eutrophication for coastal seawater.

3) Data obtained from the field survey and laboratory analysis show that the interaction of the tide and river flow strongly influence on the distribution of the concentration of major nutrients and other environmental components in seawater in the study sea area. During flood tide, seawater with low nutrient concentration infiltrates the study sea area and lowers nutrient concentration at observational points. On the other hand, during ebb tide, the river water with high nutrient concentration extends to the sea direction and raises nutrient concentration at observational points.

4) Data from the observation can be used in verifying a numerical model for the transport of organic pollutants and nutrients in a coastal sea, which helps study the interaction of river flow and the tide in a complex coastal sea, like the sea area outside Nam Trieu estuary and Lach Huyen.

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