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ASSESSMENT OF LONGITUDINAL VARIATION OF TROPHIC LEVELS OF THE RED RIVER WATER, THE SECTION FROM HANOI CITY TO BA LAT ESTUARY

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Abstract. The Red river system is a typical example of Southeast Asian rivers that is strongly impacted by human and climatic conditions, especially in the recent period. In this paper, we aim to investigate the longitudinal variation of the water quality of the Red river, in the section from Hanoi city to the Ba Lat estuary. The sampling campaigns were conducted in the dry seasons in 2017 and 2018. The monitoring results showed that the average concentrations of nutrients (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}) were still lower than the allowed values of the Vietnamese standard limits for surface water quality (QCVN 08:2015/BTNMT, column A1) whereas the average concentrations of Cl^- and TSS exceeded the allowed values of the QCVN 08:2015/BTNMT, column A1 4.6 and 2.3 times, respectively. NO_3^- and dissolved silica (DSi) concentrations showed a significant variation from the Hanoi site to the Ba Lat site (6.62 mg/l to 1.19 mg/l for NO_3^- and 5.21 mg/l to 2.14 mg/l for DSi) whereas SO_4^{2-}, NO_2^- and Cl^- increased markedly in this longitudinal section, especially from the point SH6 where the salinity started to increase. Based on the three different methods for classification of trophic levels and on the different variables observed during the dry seasons in 2017–2018, the nutrient concentrations of the Red river water tended to slightly increase from the site Hanoi (SH1) to the site SH5 at Nam Dinh, indicating the increase of nutrient external input along the river whereas it tended to decrease from the site SH6 (at mesotrophic/eutrophic level) to the last observed site SH9 (at oligotrophic/mesotrophic level) at the sea due to the dilution of seawater. Seawater in dry season could affect directly the river downstream about 35 km far from the sea. The results may be a guide for planning of water use including agricultural irrigation in the Red river estuary.

Keywords: Nutrients, river water quality, Red river, trophic level, seawater.

INTRODUCTION

The Red river is a typical example of a Southeast Asian river system, which is strongly impacted by both natural conditions and human activities, especially in the recent period. In Vietnam, the Red river is one of the nine major river systems that is used for multi-purposes, including for domestic water demand and agricultural irrigation. However, the observation of the Red river water quality is still limited, excepted for those focusing on the delta area [1, 2] or some sparse observations for

the water quality of the upstream Red river [3–5]. This paper presents the results of the longitudinal observation of the water quality of the main downstream Red River branch, in the section from Hanoi city to the sea (the Ba Lat estuary), in the dry seasons in 2017–2018. Different variables of water quality were observed in order to better characterize the water quality of the Red river downstream and then different methods were used for classification of trophic level of this river section. The results may contribute to the database construction and to assessment of the change of the Red river water quality under various changes including human-induced and climate changes in the Red river basin in recent years.

METHODOLOGY

Study area. The Red river (156.450 km^2) includes three major tributaries Da, Lo and Thao rivers, which join at Viet Tri city, and then form a large delta before flowing into the sea through four distributaries called Ba Lat, Lach Gia, Tra Ly and Day [6]. The river section from Viet Tri to Ba Lat is about 220 km. Higher river discharge was observed in the rainy season (May to October) than in the dry season (November to next April).

According to the General Statistics Office (2016) [7], there are more than 21,100 inhabitants in the Red river delta that is the most populated area in Vietnam (> 1,000 inhabitants/km^2). Population has increased in both rural and urban areas in the whole Red river basin. In this region, in terms of economy, proportion of cultivation has been reduced whereas husbandry, aquaculture, and some industries have been accelerated [3].

Recently, a series of dams has been impounded in both China and Vietnam territories of the Red river basin, which leads to a significant reduction of suspended solids from the Red river to the sea, especially in the period 2010s that may affect nutrient and trophic level of the downstream river [8].

Water sampling and analysis

Sampling campaigns and sample treatment. River water samples were taken in December 2017 and January 2018 at nine sites along the Red river from Hanoi city to the Ba Lat estuary (table 1, fig. 1). The samples were conducted by the Vietnam Standard method TCVN 6663-6: 2008 and then were preserved by the method TCVN 5993: 1995.

Table 1. Sampling sites for observation of water quality along the Red river (Hanoi to Ba Lat)

Site name	Site description	Position	Distance to Ba Lat sea
SH 1	Chuong Duong bridge, Hanoi	21°2'20"N 105°51'53"E	164 km
SH 2	Dai Gia, Phu Xuyen, Hanoi	20°46'47.3"N 105°56'49.6"E	123 km
SH 3	Moc Bac, Duy Tien, Ha Nam	20°42'4.8"N 106°0'9.1"E	111 km
SH 4	Dao Ly, Ly Nhan, Ha Nam	20°36'2.7"N 106°4'30.8"E	96 km
SH 5	Chan Ly, Ly Nhan, Ha Nam	20°28'46.4"N 106°11'11.1"E	73 km
SH 6	Xuan Chau, Xuan Truong, Nam Dinh	20°22'12.2"N 106°20'37.8"E	35 km
SH 7	Hong Thuan, Giao Thuy, Nam Dinh	20°17'15.0"N 106°28'08.0"E	17 km
SH 8	Giao Thien, Giao Thuy, Nam Đinh	20°17'26.9"N 106°32'54.6"E	6 km
SH 9	Ba Lat estuary/sea, Giao Thien, Giao Thuy, Nam Dinh	20°14'49.7"N 106°35'11.9"E	0 km

Fig. 1. Sampling sites along the Red river

Sample analysis. A water quality checker, model WQC-22A (TOA, Japan), was used to measure physico-chemical variables such as temperature, pH, conductivity, salinity and dissolved oxygen (DO) of the river water.

Water samples were filtered through Whatman GF/F paper for analyzing nitrite, nitrate, ammonia, phosphate and dissolved silica (DSi). Nutrient (N, P, Si) concentrations were spectrophotometrically determined by an UV-VIS V-630 (JASCO, Japan) by different methods described in Le et al., [9]. TSS was quantitatively determined on pre-weighed filter paper. Chlorophyll a (Chl a) was determined on Whatman GF/C filter paper by the Lorenzen method [10]. Each sample was analyzed in triplicate and value was the average.

Assessment of tropic levels of the Red river water. To assess nutrient levels and trophic status of the Red river water, the three methods i) MT1 by Primpas et al., [11]; ii) MT2 proposed by Vollenweider et al., [12]; and iii) MT3 by Carlson [13, 14] were applied. The details are as follows:

i) MT1 was based on the EI value which was calculated by the following formula and then referenced by table 2 for trophic level assessment [11]:

$$EI = 0.279C_{PO_4} + 0.261C_{NO_3} + 0.296C_{NO_2} + 0275C_{NH_4} + 0.214C_{Chl\,a}$$

Table 2. *EI* value for water quality assessment

Trophic status *EI*	Lower limit	Upper limit
Oligotrophy	0.04	0.38
Mesotrophy	0.37	0.87
Eutrophication	0.83	1.51

ii) MT2 was based on the trophic index (*TRIX*) value which was calculated by the following formula and then referenced by table 3 for trophic level assessment [12]:

$$TRIX = \frac{\left[log\left(Chl\ a*(D\%)O_2*TN*TP\right) + 1.5\right]}{1.2}$$

Table 3. TRIX value for water quality assessment

***TRIX* value**	**Status**
< 4	Elevated
4.0–5.0	Good
5.0–6.0	Mediocre
> 6.0	Bad

iii) MT3 was based on the trophic state index (*TSI*) value which was determined by the following formula and then referenced by table 4 for classifying trophic levels [13, 14]:

$$TSI = (TSI(TN) + TSI(TP) + TSI(Chl\ a))/3$$

Where:

$$TSI(Chl\ a) = 9.81\ \ln(Chl\ a) + 30.6$$

$$TSI(TP) = 14.42\ \ln(TP) + 4.15$$

$$TSI(TN) = 14.43\ \ln(TN) + 54.45$$

In the three formulas: *Chl a*: Chlorophyll a concentration (in μg/l); $(D\%)O_2$: The % deviation of the oxygen concentration from saturation conditions (abs [100%-%O]); *TN*: Total nitrogen concentration (in mg/l for *TSI* calculation, in μg/l for *TRIX* calculation); *TP*: Total phosphorus concentration (in μg/l).

Table 4. TSI value for classifying trophic levels

***TSI* value**	**Status**
0	Ultra-oligotrophic
< 40	Oligotrophic
40–50	Mesotrophic
> 50	Eutrophic
100	Hyper-eutrophic

Statistical analysis. The statistical software SPSS version 20 [15] was applied to calculate the Pearson correlation coefficients for assessing the relationship of different water quality variables.

RESULTS AND DISCUSSIONS

Variables of water quality along the Red river

Physico-chemical variables. The mean value of water temperature was 19.4°C over the whole study period. pH varied from 6.9–7.8 with an average value of 7.4. Conductivity (from 18.8 to 2035.0 mS/m**)** and salinity (from 0.01 to 1.13%) tended to increase, notably from the site SH6 towards the sea. DO varied from 5.8 to 7.3 mg/l. TSS was in high range, from 18.6 to 89.0 mg/l with an average of 47.1 mg/l which was 2.3 times higher than the allowed values of the QCVN 08:2015/BTNMT, column A1.

Table 5. Mean values of physico-chemical variables of the Red river water (from Hanoi to Ba Lat)

Site name	pH	T°C	DO (mg/l)	Conductivity (mS/m)	Salinity (%)	TSS (mg/l)
SH 1	7.8	19.8	7.3	18.8	0.010	58.2
SH 2	7.2	19.3	6.7	23.3	0.012	18.6
SH 3	7.2	19.0	6.8	28.4	0.014	21.4
SH 4	7.2	19.4	6.3	20.4	0.010	26.2
SH 5	6.9	19.5	6.4	22.5	0.012	53.2
SH 6	7.5	19.4	6.7	20.9	0.011	42.8
SH 7	7.6	19.7	5.8	114.1	0.057	55.5
SH 8	7.6	19.3	6.5	685.0	0.365	89.0
SH 9	7.7	19.6	6.8	2035.0	1.130	58.9
QCVN 08:2015 col. A1	*6.0–8.5*	-	*≥ 6*	-	-	*20*

Nutrients (N, P, Si)

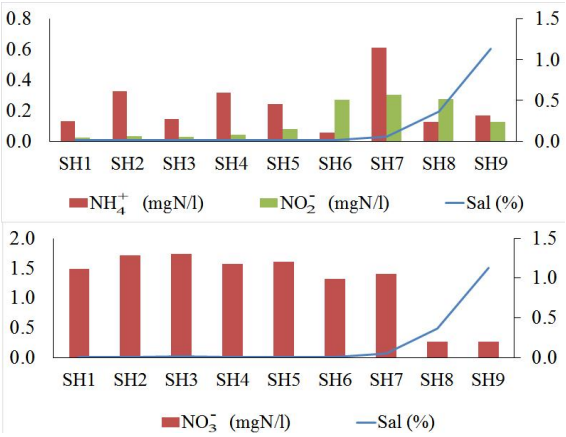

Fig. 2. Longitudinal variation of ammonium, nitrate and nitrite contents and salinity of the Red river downstream (from Hanoi to Ba Lat)

Nitrogen: Nitrite, nitrate and ammonium concentrations varied from 0.002–0.304 mgN/l; 0.268–1.734 mgN/l and 0.057–0.610 mgN/l, respectively. The average concentrations of nitrite (0.1 mgN/l), of nitrate (1.3 mgN/l) and of ammonium (0.2 mgN/l) were still lower than the allowed values of the Vietnamese standard limits for surface water quality (QCVN 08:2015/BTNMT column A1). From Hanoi to Ba Lat, nitrate significantly varied (from Hanoi: 6.62 mgN/l to Ba Lat: 1.19 mgN/l) whereas nitrite showed a clear increase, especially from the site SH6 where salinity increased (fig. 2). This reflected the influence of seawater intrusion in the downstream Red river, about 35 km far from the sea.

The average concentration of NO_3^- and NH_4^+ in the present study were 2.1 and 2.2 times higher than the ones observed in the 2012–2013 survey (NO_3^-: 0.58 mgN/l and NH_4^+: 0.09 mgN/l) for the upstream Red river [16]. The inorganic nitrogen concentration in this study was far lower than the ones of peri-urban river, e.g. the Nhue river [17], but higher than the ones of other estuaries, e.g. Lach Huyen, Van Uc, Thai Binh [18].

Phosphate and total phosphorus (Ptot):

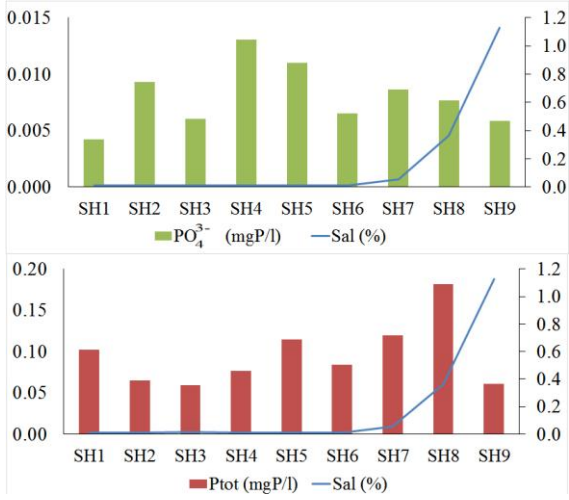

Fig. 3. Longitudinal variation of PO_4^{3-} and Ptot contents and salinity of the Red river downstream (from Hanoi to Ba Lat)

Phosphate concentrations varied from 0.004–0.013 mgP/l and averaged 0.008 mgP/l for all sites and were still lower than the allowed values of the QCVN 08:2015/BTNMT

column A1 (0.1 mgP/l). Higher phosphate concentrations at SH4 and SH5 sites reflected the impact of domestic wastewater from the Yen So pumping station in Ha Noi city (fig. 3). The average concentrations of phosphate in this study were much lower than the one observed for other estuary (e.g. 0.052 mgN/l) [18].

Ptot concentrations were much higher, from 0.059–0.181 mgP/l, averaging 0.1 mgP/l. However, no clear longitudinal variation of total phosphorus concentrations in the Red river downstream was observed (fig. 3).

Dissolved silica (DSi): DSi concentrations in rivers mainly originate from rock weathering, and therefore depend on the lithology of the basin [19]. The lithological composition of the Red river watershed is dominated by sedimentary rocks with about half of carbonated rocks. This may reflect DSi concentrations which varied from 2.1 to 5.2 mgSi/l, averaged 4.5 mgSi/l at all sites. DSi content significantly decreased since the site SH6 where salinity increased (at Hanoi: 5.2 mg/l; at Ba Lat: 2.1 mg/l) (fig. 4).

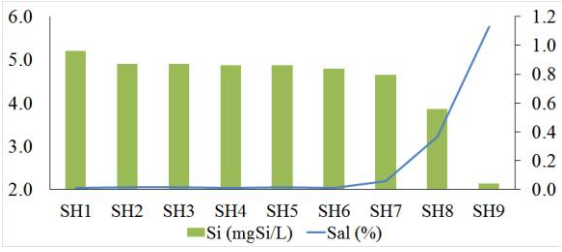

Fig. 4. Longitudinal variation of DSi content and salinity of the Red River downstream (from Hanoi to Ba Lat)

Chloride and sulfate. Chloride concentrations varied largely from 7.9 mg/l to 6762 mg/l, averaging 1022 mg/l for all sites, which exceeded the allowed values of the QCVN 08:2015/BTNMT column A1 (250 mg/l) 4.6 times. Sulfate concentration also highly fluctuated from 6.7 to 251.5 mg/l with an average of 51.8 mg/l. Chloride and sulfate concentrations tended to increase along the river from the first site at Hanoi city towards the sea (from Hanoi to Ba Lat), especially from SH6 to SH9, reflecting the clear impact of seawater.

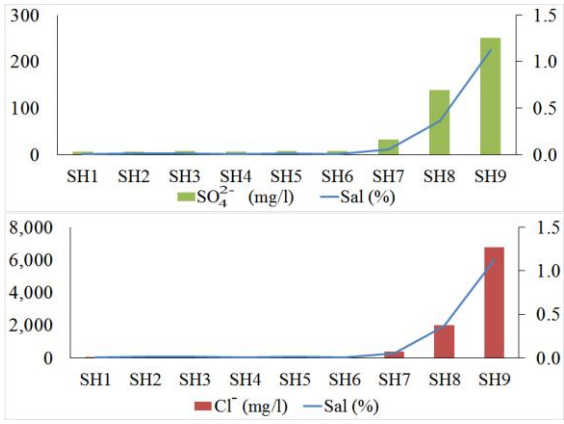

Fig. 5. Chloride and sulfate concentrations and salinity of the Red river water (from Hanoi to Ba Lat)

Chlorophyll a. Chlorophyll a (Chl a) concentrations varied largely from 0.12–1.18 µg/l and averaged 0.30 µg/l for all sites. Chl a concentrations tended to increase from SH1 (Hanoi) to SH5 (Ha Nam), then showed a clear decrease from SH6 to SH9 (fig. 6). This trend was similar to the phosphate concentration variation along the Red river.

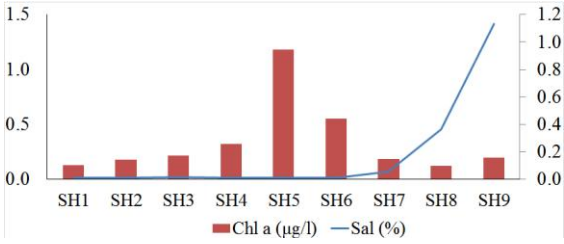

Fig. 6. Chlorophyll a concentrations in the Red river water (from Hanoi to Ba Lat)

The mean value of Chl a in this study (0.3 µg/l) was lower than the one observed at Hanoi site (1.97 µg/l) in the previous study [16], indicating the low phytoplankton development in river water, probably due to the lower temperature during the observation study period (in December and January).

Relationship between some variables of water quality along the Red River. The analysis results of the Pearson correlation showed that the salinity was strongly positively correlated with sulfate (R2 = 0.94) and chloride

(R2 = 0.99) concentrations whereas it showed a negative correlation with nitrate and silica, also reflecting the impact of seawater to the Red river downstream in the dry season.

Chlorophyll a was positively correlated with phosphate (R2 = 0.57), indicating that the algae growth strongly depended on phosphate concentration in the Red river downstream. Total phosphorus is known to be associated with total suspended solids TSS in river water and in this study, it also showed a positive correlation with TSS (R2 = 0.71) (table 6). Thus, the reduction of TSS concentrations and flux of the lower Red river downstream due to the dam impoundment as reported recently [8] may lead to further reduction of total phosphorus concentrations and flux that may affect the Red river estuary and coastal zone. Further detailed study on the change of phosphorus flux at the Red river estuary and coastal zone may be necessary for the next step.

Table 6. Pearson correlation for relationship between some variables of water quality along the Red river

Variables	pH	Salinity	NO_3^-	DSi	PO_4^{3-}	Ptot	SO_4^{2-}	Cl^-	Chl a	TSS
pH	1									
Salinity	0.39	1								
NO_3^-	-0.45	**-0.71**	1							
DSi	-0.29	**-0.93**	**0.83**	1						
PO_4^{3-}	-0.44	-0.21	0.37	0.25	1					
Ptot	0.24	-0.07	-0.22	0.09	0.30	1				
SO_4^{2-}	0.42	**0.94**	**-0.85**	**-0.92**	-0.24	0.10	1			
Cl-	0.37	**0.99**	**-0.72**	**-0.93**	-0.22	-0.08	**0.95**	1		
Chl a	-0.44	-0.20	0.33	0.27	**0.57**	0.34	-0.21	-0.19	1	
TSS	**0.53**	0.33	**-0.53**	-0.32	-0.08	**0.71**	0.43	0.32	0.10	1

Classification of nutrient levels in the Red river section from Hanoi city to Ba Lat estuary

Table 7. Classification of nutrient levels of the Red river water (from Hanoi to Ba Lat) by the three different methods

Site	*TSI* value and trophic status	*TRIX* value and trophic status	*EI* value and trophic status
SH1	45.4 Mesotrophy	5.7 Mediocre	0.45 Mesotrophy
SH2	47.8 Mesotrophy	6.1 Bad	0.59 Mesotrophy
SH3	47.5 Mesotrophy	6.1 Bad	0.55 Mesotrophy
SH4	50.1 Eutrophy	6.4 Bad	0.58 Mesotrophy
SH5	56.4 Eutrophy	7.0 Bad	0.76 Mesotrophy
SH6	51.7 Eutrophy	6.5 Bad	0.56 Mesotrophy
SH7	51.4 Eutrophy	6.5 Bad	0.67 Mesotrophy
SH8	45.5 Mesotrophy	5.8 Mediocre	0.21 Oligotrophy
SH9	42.0 Mesotrophy	5.6 Mediocre	0.20 Oligotrophy

Based on the monitoring results on nutrients and Chl a concentrations, we calculated the trophic index values by the three methods presented in the section "*Assessment of tropic levels of the Red river water*".

The calculation results of all three methods showed that the trophic level of the Red river water tended to slightly increase from the site Hanoi (SH1) to the site SH5 at Nam Dinh, indicating the increase of nutrient external input along the river whereas it tended to decrease from SH5 (mesotrophic/eutrophic level) to the last site SH9 (oligotrophic/mesotrophic level) at the sea due to the dilution of seawater (table 7). For more details, from SH1 to SH5, river received different nutrient external inputs such as domestic and industrial wastewater as well as agricultural release that may enrich nutrients in river, especially in dry season when the river discharge is much lower than that in the wet season.

CONCLUSION

The observation results of the Red river downstream from Hanoi to Ba Lat in dry seasons 2017–2018 showed that almost all the variables were within the allowed values of the Vietnamese standard limits for surface water quality (QCVN 08:2015/BTNMT, column A1), except for the chloride and TSS concentrations. The SO_4^{2-}, NO_2^- and Cl^- concentrations increased markedly in this longitudinal section, especially from the point SH6 where the salinity started to increase. In contrast, NO_3^- and DSi concentrations showed a significant longitudinal variation from Hanoi to Ba Lat. The results revealed that seawater in dry season could affect directly the river downstream about 35 km far from the sea. The Pearson correlation results enhanced this outcome. The relationship between different variables of the Red river quality found in this study may open the further study for the next step of the nutrient and suspended solid fate in the Red river estuary and coastal zone.

The calculation of trophic levels at 9 sites along the Red river by the three different methods showed that the nutrient concentrations of the Red river water tended to slightly increase from the site Hanoi (SH1) to the site SH5 at Nam Dinh, indicating the increase of nutrient external input along the river whereas it tended to decrease from the site SH6 (at mesotrophic/eutrophic level) to the last observed site SH9 (at oligotrophic/mesotrophic level) at the sea due to the dilution of seawater.

The results may provide a guide for water utilization as the reduced nitrate and DSi concentrations together with the increased salinity at the downstream Red river (about 35 km far from the sea) which may not be suitable for agricultural irrigation or some other water utilization purposes.

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