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Assessment of Coastal Surface Water Quality in Southern Vietnam

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Abstract

The study was carried out to assess the water quality in estuaries and coastal waters in the South of Vietnam. Water samples were collected at 12 locations denoted from S1 to S12, in which locations from S1 to S6 belong to the estuary while positions from S7 to S12 belong to the sea. Samples were collected 6 times from April to September. Temperature, pH, DO, EC, TSS, N-NH_4^+, P-PO_4^{3-} and Fe were used for water quality assessment by comparing with National technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT). Cluster and principal component analyses were used to identify frequency, potential polluting sources, and key variables influencing coastal water quality. The results show that estuary water was polluted mainly by TSS and Fe. DO, N-NH_4^+, P-PO_4^{3-} at some locations exceeded the allowed standards. For water quality in coastal estuaries, N-NH_4^+, Fe, TSS, DO at several locations exceeded the allowable limits. Low DO indicated that the coastal water was organically polluted. P-PO_4^{3-} was still within the allowable limit. TSS, N-NH_4^+, EC were subjected to seasonal variation. PC1, PC3, and PC3 explained 86.5% variation, were the main sources of water quality variation. PCA also showed that temperature, pH, DO, EC, TSS, N-NH_4^+, P-PO_4^{3-} and Fe were key variable influencing on water quality and need to be further monitored. CA showed that water quality monitoring in coastal areas can be reduced from 6 sampling times to 3 times, saving 50% of the monitoring costs.

1. Introduction

Southern Vietnam is a dynamic economic region with high economic growth rate, with the largest industrial, business and service development activities in the country, where many industrial parks and clusters are concentrated. industry and many industrial and handicraft production facilities of different sizes and industries are widely dispersed in the localities. The development of industrial zones and clusters is not synchronized with the technical infrastructure conditions on the environment; many industrial zones and clusters have not yet invested in centralized wastewater treatment systems, causing environmental pollution [1]. Mining activities in many localities lack of strict management, increasing hotspots of environmental pollution [1]. The rate of collection and treatment of solid waste, medical waste, domestic and industrial wastewater in accordance with regulations is still low; Exhaust gas and dust arising from uncontrolled transportation, construction and production facilities have been causing serious environmental pollution in big cities and river basins. Wastes from agricultural production and daily life of people in rural areas are not collected and treated properly and hygienically; the widespread use of chemical fertilizers and pesticides, leading to an increase in rural environmental pollution, in some places is very serious [2].

Environmental pollution in handicraft villages is still difficult to control, handle and overcome, and in some places it is becoming more and more serious. The state of outdated technology, waste in the form of scrap imported into Vietnam is complicated [3]. Biodiversity is seriously degraded and threatened; species and genetic resources are increasingly reduced and lost; The number of endangered species continues to increase. Environmental quality in the region is increasingly degraded due to the impact of socio-economic development and climate change. Surface water sources of river basins in the region have been polluted locally, mainly in the downstream areas of main rivers, tributaries and inner-city canals, areas receiving wastewater from other areas. urban centers, industrial zones and production and business establishments in the Southern key economic region [4]. The estuary and coastal areas are the recipients of wastewater from inland economic development activities, so water quality monitoring plays an important role. Implementing the Law on Environmental Protection in 2014, environmental monitoring programs have been established in all provinces in Vietnam [4]. Water quality monitoring is an important task to manage and maintain water quality for socio-economic development. For surface water quality monitoring, physico-chemical and biological parameters can be selected [1]. In Vietnam, the assessment of surface water quality is mainly compared with Vietnamese standards and the selection of indicators is based only on funding and pollution sources. Meanwhile, in the world, multivariate analysis method is widely applied to assess water quality [5] to identify sources of pollutant generation, assess location, frequency and monitoring indicators [5]. This study aims to assess the coastal water quality, identify the main factors affecting the coastal water quality, and evaluate the sampling frequency using principal component analysis and cluster analysis. The results can provide useful information for water quality monitoring.

2. Methodology

2.1 Water sampling and analysis

Water samples were collected at 12 sites, S1 to S12. In which, S1 to S6 belong to the estuary while positions S7 to S12 belong to the sea (Table 1). The water samples were collected 6 times in April to September in 2020. The indicators for assessing water quality include temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), total suspended solids (TSS), ammonium (N-NH_4^+), orthophoshate (P-PO_4^{3-}) and iron (Fe). Water samples were collected according to the instructions of TCVN 5998:1995 (ISO 5667-9: 1992) and the preservation method was carried out according to the instructions of TCVN 5998:1995 and TCVN 6663-3:2016 (ISO 5667- 3:2012). The parameters of pH, temperature, DO, EC were measured in the field while TSS, N-NH_4^+, P-PO_4^{3-} and Fe parameters were measured in the laboratory by standard methods [6]. The analytical methods are summarized in Table 2.

Table 1. Sampling locations

No.	Sampling sites	Code	LONG	LAT
1	Can Gio sea, HCMC	S1	106^{0}55'12,8"	10^{0}23'10,6"
2	Sao Mai - Ben Dinh, HCMC	S2	107^{0}03'42,4"	10^{0}23'13,7"
3	Bai Truoc, HCMC	S3	107^{0}04'27,0"	10^{0}20'36,0"
4	Bai Sau, HCMC	S4	107^{0}05'59,7"	10^{0}20'44,5"
5	Loc An sea, HCMC	S5	107^{0}18'05,3"	10^{0}25'48,2"
6	Saigon River Estuary – Tam Thon Hiep, HCMC	S6	106^{0}45'37,0"	10^{0}44'37,0"
7	Thi Vai River Estuary, HCMC	S7	106^{0}59'46,6"	10^{0}29'28,1"
8	Nga Bay River Estuary, HCMC	S8	106^{0}56'51,1"	10^{0}30'58,2"
9	Tan Thanh beach, Tien Giang province	S9	106^{0}47'00,7"	10^{0}17'25,5"

10	Cua Lon, Soc Trang province	S10	106⁰47'47,8”	09⁰35'11,3"
11	Cua Tieu – Tien river, Tien Giang province	S11	106⁰46'03,5"	10⁰15'22,8"
12	Cua Dai – Tien river, Tien Giang province	S12	106⁰45'22,0"	10⁰11'59,5"

Table 2. Analytical methods and limit values

Variable	Unit	Analytical methods	QCVN*	QCVN**
Temp.	°C	SMEWW 2550B:2017	-	-
pH	-	TCVN 6492:2011	-	-
DO	mg/L	TCVN 12026:2018	4	5
EC	mS/cm	SMEWW 2510.B:2017		
TSS	mg/L	SMEWW 2540.D:2017	50	50
$N\text{-}NH_4^+$	mg/L	TCVN 6179-1:1996	0.5	0.1
$P\text{-}PO_4^{3-}$	mg/L	SMEWW 4500-P.E:2017	0.3	0.2
Fe	mg/L	SMEWW 3111.C:2017	0.5	0.5

*Coastal sea water used for the beach; **Used for aquaculture, aquatic conservation [7].

2.2 Data processing

Water quality was assessed using National technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT). Details of limit values are presented in Table 2. Principal component analysis (PCA) was used to evaluate the main criteria affecting water quality in the study area. PC is considered as a potential pollution source, by looking at the correlation between water quality parameters [8]. The Eigenvalue coefficient is considered as a measure of the importance of PC, which corresponds to the importance of the source of water quality fluctuations. The larger the coefficient, the more the source of water quality variation contributes to the water quality variation, and the most important components when the Eigenvalues are greater than one [9]. In addition, the weighted correlation coefficient of each PCs can help identify pollution sources and is rated at three levels of high, medium and weak, with absolute load values > 0.75, 0.75– 0.50 and 0.50 – 0.30, respectively [5]. Cluster analysis is used in grouping water quality by sampling frequency at study sites to assess sampling frequency. The cluster analysis method was performed using Euclidean distance [5]. The result of CA is reported as D_{link}/D_{max} link distance, link distance between clusters is considered to have clustering significance when $D_{link}/D_{max}\times100= 60$ [10]. All parameters and frequencies were used in this analysis, the sampling frequency is considered as group variable (dependent variable), the water parameters are considered as independent variable. These analyzes were performed using Statgraphics Centurion version XVI software (Statgraphics Technologies Inc.,Virginia state, USA).

3. Results and discussion

3.1 Water quality in the study area

The temperature at the study sites ranged from 29.7 to 31.6 °C while the temperature between sampling sessions ranged from 29.2 to 31.5 °C (Figure 1). Temperature had little variation in space and time. The temperature on Tien River is in the range of 29.35-30.2°C and there was no statistically significant difference ($p>0.05$). Water temperature in Hau river ranged from 27.1 to 32.0 °C [11] and in Mekong river is from 19.9 to 32.2 °C [12-13]. There is not much difference in water temperature between freshwater and saltwater areas, possibly because water has a temperature-regulating function [12]. The suitable temperature for aquatic life is in the range of 25-32 °C [14].

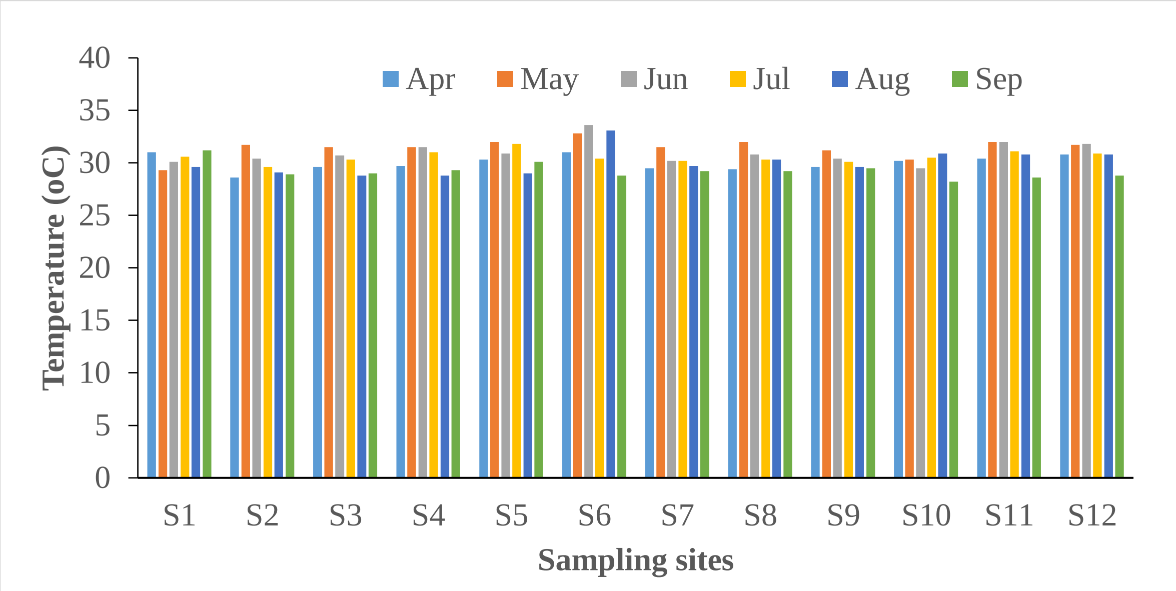

Figure 1. Temperature in coastal water in the south of Vietnam

The pH between sampling sites was in the range of 7.4-8.3 while between sampling months was in the range of 7.7-8.0 (Figure 2). Similar to temperature, pH had little variation between sampling sites. The results of monitoring the pH value in surface water in saltwater areas of Bac Lieu province in 2019 ranged from 6.98 to 9.2 [15]. pH value in surface water in Ben Tre province ranged from 6.53 to 8.02 and the average was at 7.2±0.2 [16]. The pH in saltwater areas tends to be lower than in freshwater areas because seawater is alkaline.

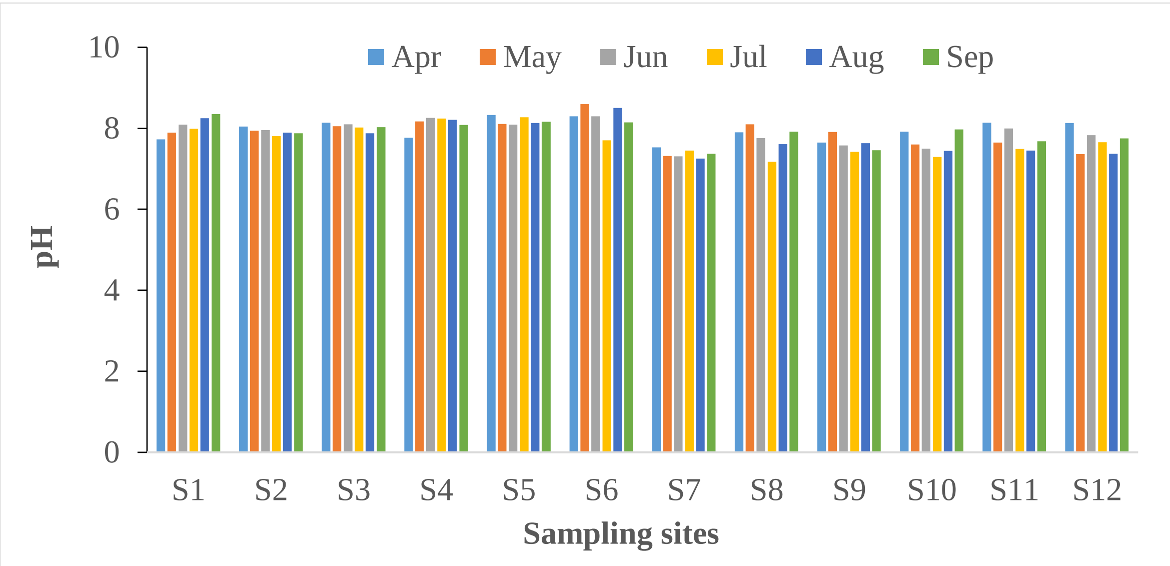

Figure 2. pH in coastal water in the south of Vietnam

The electrical conductivity (EC) of coastal and estuarine seawater at the sampling sites varied from 14.757 to 53.482 mS/cm while EC over time ranged from 29.166 to 47,317 mS/cm. Sites S6 to S12 had a decreasing EC between June and September (**Figure 3**). EC is subject to seasonal variation. EC was high in the study areas due to sea water containing high dissolved salt.

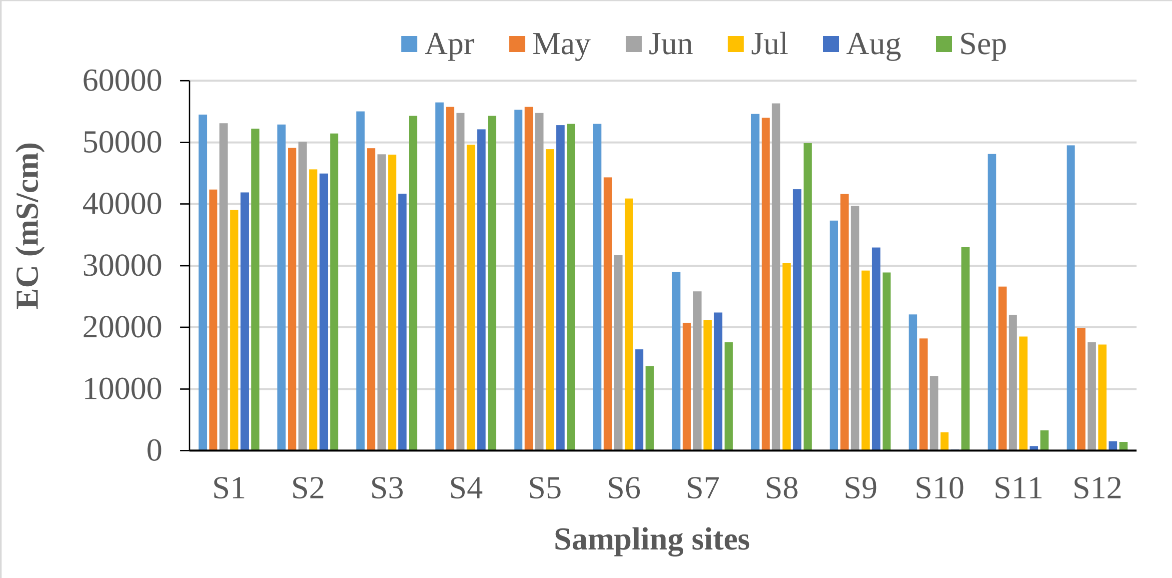

Figure 3. EC in coastal water in the south of Vietnam

The dissolved oxygen (DO) concentration in the seawater environment at different locations ranged from 4.7 to 7.4 mg/L. DO between the observational period ranged from 5.6 to 6.7 mg/L (Figure 4). DO in coastal seawater at 06 sites (S1-S6) ranged from 3.7 to 8.3 mg/L. Most of the DO values of monitoring points meet the limit of QCVN 10-MT:2015/BTNMT, which are used for beaches, water sports (DO ≥ 4 mg/L). At Sao Mai-Ben Dinh sampling point, the DO value at phase 4 (3.7 mg/L) does not meet the acceptable limit due to the impact of activities socio-economic (for examples, fishing port area, seafood processing activities). The DO values at the sampling sites S7-S12, coastal estuary area, were ranging from 4.2 to 7.4 mg/L (Figure 4). There were seven out of 36 sites with DO lower than the threshold limit of QCVN 10-MT:2015/BTNMT, which is used for aquaculture areas, aquatic conservation (DO ≥ 5 mg/L). In which, the water quality at the Sai Gon-Tam Thon Hiep estuary had a lower DO value than that in the other monitoring points. There were four out of six monitoring sites had DO lower than the prescribed standard. Former study reported that the DO value in seawater in Bac Lieu area ranged from 4 to 6.8 mg/l [15]. The DO concentration in rivers depends on diffusion, the presence of phytoplankton and organic matters [13,17-18]. According to [14], suitable DO in water is 5-7 mg/L.

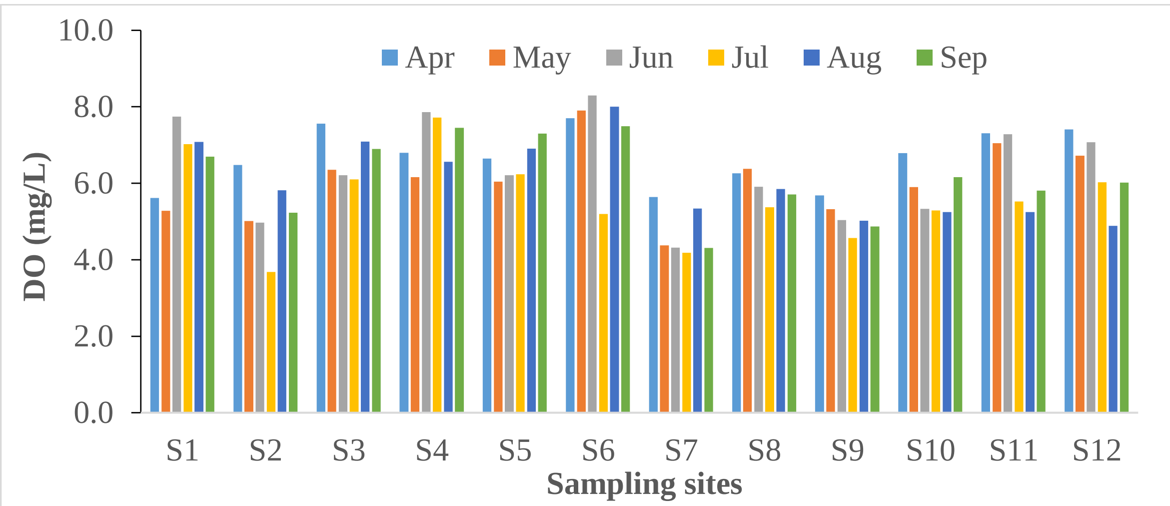

Figure 4. DO in coastal water in the south of Vietnam

The total suspended solids (TSS) concentration in space and over time fluctuated between 26.5-123.5 mg/L and 19.1-87.2 mg/L (Figure 5). TSS at positions from S1-S6 varied greatly from 3 to 230 mg/L (average 44 mg/L). There were nine out of 36 sites in which TSS concentrations exceeded the allowable limit of QCVN 10-MT:2015/BTNMT, the column which is used for beach areas, water sports. TSS at the sites S7-S12 in the coastal estuary area ranged from 4-233 mg/L and has 12/36 values exceeding QCVN 10-MT:2015/BTNMT in the area of aquaculture and aquatic conservation (TSS $\leq$ 50 mg/L). TSS in rainy season tended to be higher than that in dry season. TSS concentration in Ben Tre's water bodies was also in the range of 3.5-143.5 mg/L [16]. TSS in surface water bodies in Tien Giang province ranged from 77.7-121.8 mg/L [19]. In canals of Soc Trang province, TSS ranged from 16-176 mg/L [20]. TSS has a seasonal variation in which TSS in the wet season is usually higher than that in the dry season [18-21]. TSS pollution is a major water environmental problem in Vietnam's water bodies.

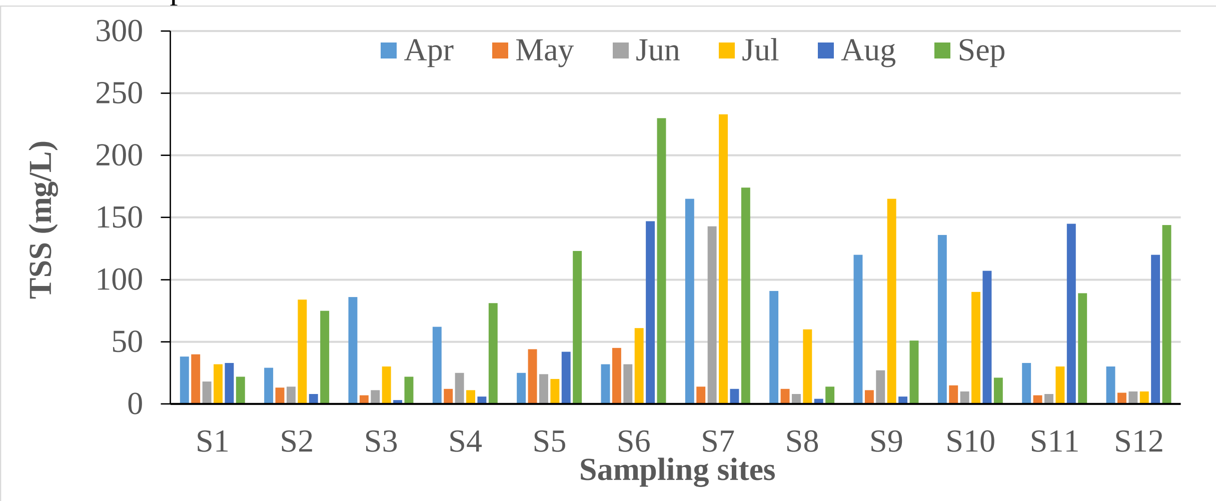

Figure 5. TSS in coastal water in the south of Vietnam

The ammonium concentration ($N\text{-}NH_4^+$) at the survey sites ranged from 0.10 to 0.22 mg/L while the $N\text{-}NH_4^+$ between samples ranged from 0.02-0.27 mg/L (Figure 6). $N\text{-}NH_4^+$ at positions S1-S6 ranged from 0.03 to 0.63 mg/L and had 02/36 values (Can Gio Sea in period 1 and Sao Mai-Ben Dinh in period 4) exceeding QCVN 10-MT:2015/BTNMT in the area of aquaculture and aquatic conservation ($N\text{-}NH_4^+$ < 0.5 mg/L) by 1.26 times and 1.14 times, respectively. The concentrations of $N\text{-}NH_4^+$ at S7-S12 ranged from 0.04 to 0.38 mg/L (Figure 6). There were 16 out of 36 sampling sites where the values of $N\text{-}NH_4^+$ exceeded the limit of QCVN 10-MT:2015/BTNMT (the column which is used for aquaculture, aquatic conservation) from 1.1 times to 3.8 times. The concentration of $N\text{-}NH_4^+$ in May and September was lower than that in the other months. The value of $N\text{-}NH_4^+$ in the salt water area of Bac Lieu province in 2019 ranged from 0.099 to 1.516 mg/l during the dry season monitoring and from 0.46 to 1.79 mg/l in the rainy season [15]. $N\text{-}NH_4^+$ in canals of Hau Giang province was 0.27±0.16 mg/L [22]. The concentration of $N\text{-}NH_4^+$ in the surface water in Ben Tre was 0-1.75 mg/L [16]. Previous studies showed that $N\text{-}NH_4^+$ fluctuated according to seasons in which the rainy season was usually higher than that in the dry season [19-21]. The results show that $N\text{-}NH_4^+$ in inland canals is often higher than that in coastal areas.

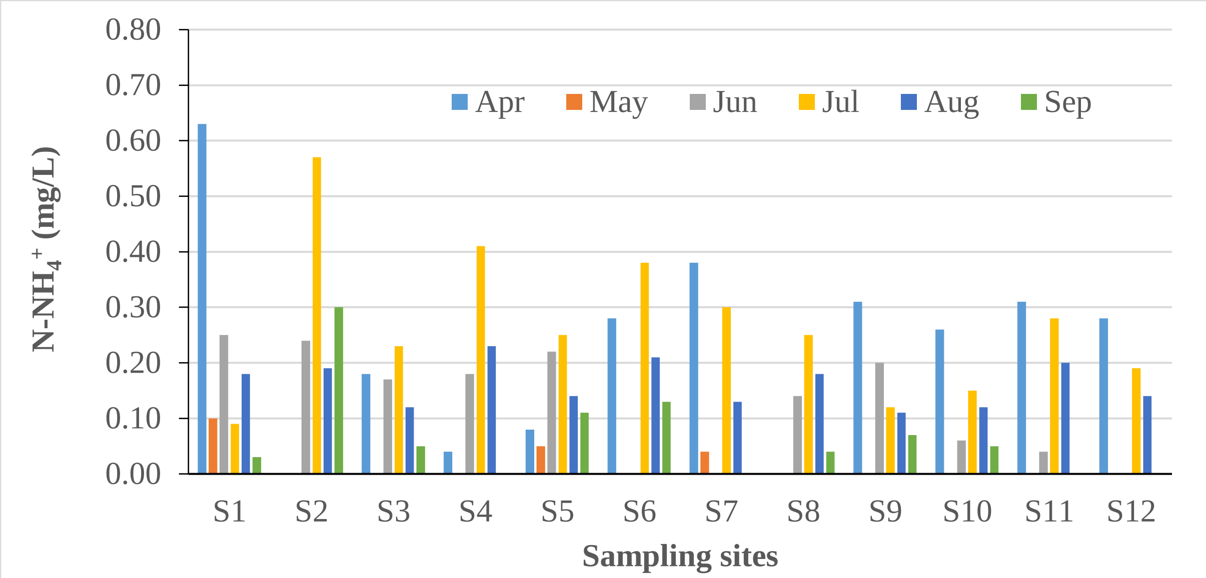

Figure 6. N-NH$_4^+$ in coastal water in the south of Vietnam

The orthophosphate concentration (P-PO$_4^{3-}$) over time and space fluctuated between 0.03-0.09 mg/L and 0.03-0.11 mg/L (Figure 7). P-PO$_4^{3-}$ concentrations at locations S1 to S6 ranged from 0 to 0.32 mg/L. P-PO$_4^{3-}$ at Tan Thanh Beach in the 6th sampling period exceeded the limit of QCVN 10-MT:2015/BTNMT (which is used for beaches and water sports). Meanwhile, the value of P-PO$_4^{3-}$ at S7-S12 fluctuated in the range of 0.03 - 0.42 mg/L and has 01/36 values (Cau Dai-Song Tien in phase 5/2020) surpassing QCVN 10- MT:2015/BTNMT, column in beach area, water sports (P-PO$_4^{3-}$ $\geq$ 0.3 mg/L). P-PO$_4^{3-}$ ranged from 0.092 to 0.852 mg/l in the coastal water environment of Bac Lieu province [15]. P-PO$_4^{3-}$ concentration in Ben Tre's water bodies ranged from 0 to 0.587 mg/L [16] and in Tien Giang's water bodies ranged from 0.1 ± 0.2 to 0.1 ± 0.1 mg/L [19]. Previous studies have shown that P-PO$_4^{3-}$ has little seasonal variation [19-21]. As can be seen that P-PO$_4^{3-}$ is highly varied depending on water bodies.

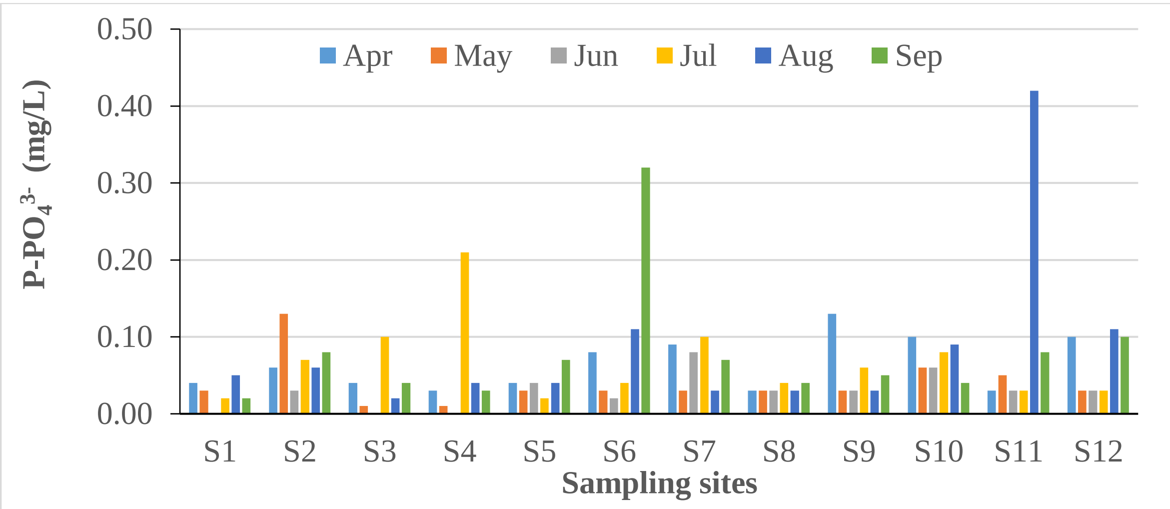

Figure 7. P-PO$_4^{3-}$ in coastal water in the south of Vietnam

The Fe concentration at the study sites ranged from 0.19 to 1.80 mg/L while the Fe through the sampling sessions ranged from 0.22 to 1.09 mg/L **(Figure 8)**. Fe value at S1-S6 fluctuates from

0 to 1.3 mg/L and has 14/36 values exceeding QCVN 10-MT:2015/BTNMT in beach areas, water sports (Fe ≤ 0.5 mg/L). Similar to TSS, Fe also had the highest value at Tan Thanh Beach and all 6 monitoring periods exceeded the allowable standard from 1.2 times to 2.5 times. Fe value at S7-S12, estuary area, ranged from n0 to 3.5 mg/L and has 11/36 values exceeding QCVN 10-MT:2015/BTNMT, column for aquaculture and aquatic conservation areas. (Fe ≤ 0.5 mg/L). The estuary site of Sai Gon - Tam Hiep Thon estuary showed a sudden increase in Fe values of the 1st, 3rd and 4th stages of the year compared to the rest of the year and exceeded QCVN 10-MT:2015/BTNMT (aquaculture area column, aquatic conservation) from 2.3 times to 6.9 times. Fe in surface water in saline waters of Bac Lieu province in 2019 fluctuated in the range of 0.111 – 4.842 mg/l [15]. In Soc Trang, Fe concentration in surface water was from 0.30-3.75 mg/L [20]. Fe concentration in water bodies in Ben Tre province was 0 to 5.38 mg/L [16]. High Fe is due to alkaline soil, rock materials as well as from industrial research [21].

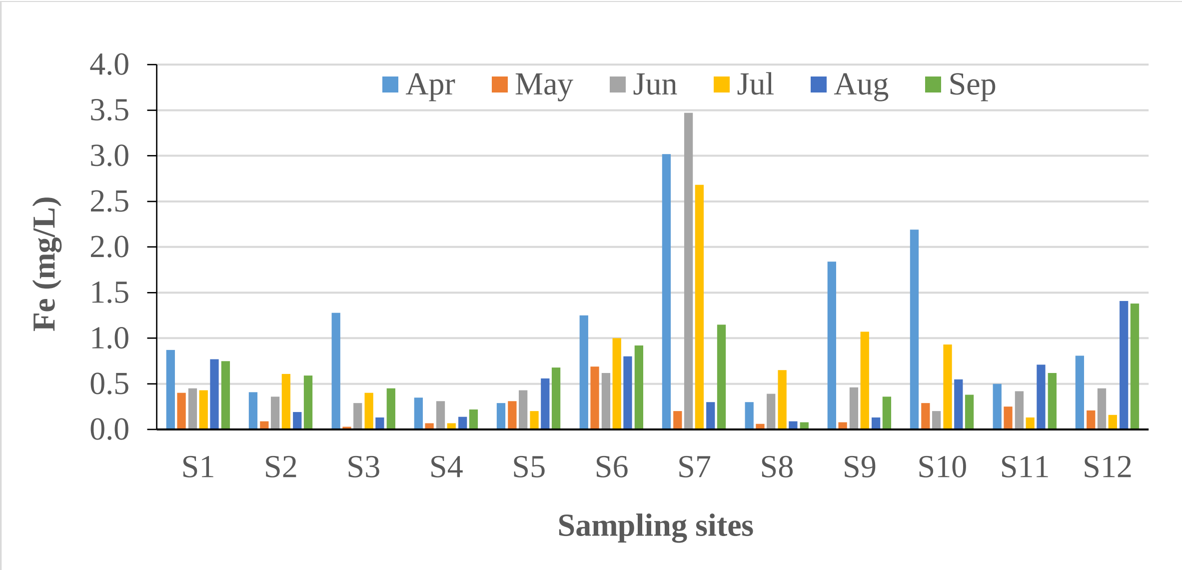

Figure 8. Fe in coastal water in the south of Vietnam

3.2 Main factors affecting water quality in the study area

The PCA results showed that the variation in water quality in the study area was explained by 8 PCs **(Table 3)**. In which, PC1-PC3 has an eigenvalue coefficient greater than 1, explaining 86.5% of water quality variation. The PC4-PC8 have an eigenvalue of less than 1, which explained only 13.5% of the variation in water quality. Therefore, PC1, PC3, and PC3 were the main sources of water quality variation in the study area. Whereas the sources from PC4-PC8 were secondary sources. PC1 had a weak negative correlation with pH, EC while there was a weak positive correlation with TSS and Fe. PC was moderately positively correlated with temperature and weakly with pH, DO and P-PO_4^{3-}. PC3 has a good positive correlation with N-NH_4^+. PC4 has a moderate positive correlation with P-PO_4^{3-} while a weak negative correlation with TSS and Fe. PC5 has a moderate correlation with EC and DO while a weak correlation with temperature and Fe. PC6 was moderately correlated with temperature but weakly correlated with pH, P-PO_4^{3-}, N-NH_4^+. PC7 had a moderate correlation with pH but a weak correlation with EC and DO. PC8 had a moderate correlation with TSS, Fe while it had a weak correlation with pH and DO. The temperature affected by PC2, PC5, PC6 showing that there were many factors affecting the temperature in the study area. pH was affected by 5 PCs, EC was affected by 3 PCs, DO was affected by 3 PCs, TSS was affected by 3 PCs, P-PO_4^{3-} was affected by 3 PCs, N-NH_4^+ was affected by 3 PCs. Fe was influenced by 4 PCs. The results showed that water quality indicators were simultaneously affected by many pollution sources. The parameters of temperature, pH, DO, EC, TSS, N-NH_4^+, P-PO_4^{3-} and Fe all had major impacts on water quality in the study area and need to be further monitored. There may be many other factors that can affect water quality, so in the coming time, it is necessary to expand monitoring indicators to have a more comprehensive assessment of water quality.

Table 3. Main factors affecting water quality in the study area

Variables	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**
Temp.	-0.026	**0.643**	-0.082	-0.178	**0.312**	**0.664**	0.010	0.098
pH	**-0.440**	**0.309**	0.216	-0.139	-0.027	**-0.355**	**-0.634**	**0.341**
EC	**-0.446**	-0.185	0.240	-0.305	**0.577**	-0.182	**0.492**	0.086
DO	-0.332	**0.477**	-0.169	-0.151	**-0.504**	-0.257	**0.423**	**-0.335**
TSS	**0.445**	0.198	0.251	**-0.377**	0.283	-0.287	-0.213	**-0.591**
P-PO_4^{3-}	0.281	**0.434**	0.112	**0.616**	0.261	**-0.392**	0.254	0.235
N-NH_4^+	-0.150	0.001	**0.839**	0.272	-0.236	**0.311**	0.053	-0.213
Fe	**0.444**	0.041	0.285	**-0.488**	**-0.333**	-0.047	0.253	**0.552**
Eigen.	3.58	2.14	1.20	0.69	0.20	0.15	0.03	0.01
%Var	44.8	26.7	15.0	8.6	2.6	1.8	0.4	0.2
Cum.%Var	44.8	71.5	86.5	95.0	97.6	99.4	99.8	100.0

3.3 Classification of water quality by sampling frequency

The results of cluster analysis showed that at the Euclidean distance = 3, six sampling periods were divided into three clusters. Cluster 1 includes the months of July, August, and September. These are the months representing the rainy season. Meanwhile, cluster 2 has only one month of April (the month representing the dry season). Cluster 3 is the months of May and June. For cluster 1, the temperature, EC, and DO were lower than that of clusters 2 and 3. Besides, P-PO_4^{3-} of cluster 1 tended to be larger than that in the remaining clusters. Cluster 2 was characterized by EC was higher than that in cluster 1 and cluster 3. TSS, P-PO_4^{3-}, N-NH_4^+ and Fe of cluster 2 were higher than that in cluster 3. Cluster 3 had EC higher than that in cluster 1 while all other remaining parameters were lower than those of cluster 1 and cluster 2. The results of cluster analysis showed that water quality monitoring in coastal areas only needs to be sampled in April, June and September to be representative of water quality in the study areas.

Figure 9. Clustering surface water quality in the coastal area

4. Conclusions

The results showed that the coastal sea water quality in the southern region in 2020 had high TSS and Fe concentrations, especially in Tan Thanh beach area. Water quality in coastal estuaries was locally polluted by the parameters of N-NH_4^+, Fe, TSS and DO. In general, the Southeast region (Saigon River Estuary - Tam Thon Hiep, Thi Vai Estuary, Nga Bay Estuary) had better quality than the Southwest region (Cua Lon, Cua Dai - Song Tien, Cua Tieu, Cua Lon, Cua Dai - Song Tien, Cua Tieu – Song Tien), in which the location of Thi Vai estuary has stable water quality and is better than the other 5 monitoring locations. TSS, N-NH_4^+, EC were seasonally varied while the other indicators were not significanly differed. The parameters of temperature, pH were still within the allowable limits of Vietnamese standards for coastal waters. PC1, PC3, and PC3 were the main sources of water quality variation contributed to explain 86.5% variation of water quality in the study area. The parameters of temperature, pH, DO, EC, TSS, N-NH_4^+, P-PO_4^{3-} and Fe all had major impacts on water quality in the study area and need to be further monitored. The results of cluster analysis showed that water quality monitoring in coastal areas only needs to be sampled in April, June and September to represent water quality in the study areas. The main cause of water pollution in estuaries and coastal sea water is due to socio-economic development activities of the study area. There may be many other factors that can affect water quality, so in the coming time, it is necessary to expand monitoring indicators to have a more comprehensive assessment of water quality.

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